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LOW-COST, SELF-HOSTED SECURE ACCESS SERVICE EDGE (SASE) SOLUTION USING AWS CLOUD INFRASTRUCTURE

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ABSTRACT

The proliferation of remote work and the need for secure, private access to corporate resources have heightened the necessity for robust Virtual Private Network (VPN) solutions, particularly for organizations handling sensitive data. This research paper introduces a low-cost, self-hosted Secure Access Service Edge (SASE) solution, utilizing cloud infrastructure to establish a scalable enterprise-grade VPN. The proposed system is entirely developed using open-source tools and operates across three Amazon Web Services (AWS) Virtual Private Clouds (VPCs) located in different geographic regions.

Our methodology leverages a combination of pfSense for network security, OpenVPN for establishing secure tunnels, and iPerf for monitoring network performance. This blend of technologies ensures a comprehensive approach to network security and management, providing an end-to-end solution that maintains privacy and data integrity without the financial burden of commercial VPN services. The key to our approach is the integration of these tools within AWS's scalable environment, facilitating secure communication channels between distributed resources while enabling effective network management and threat mitigation. The system's architecture is designed to be both resilient and flexible, accommodating the dynamic needs of enterprises without compromising on security. Through the strategic placement of VPCs in different AWS regions, we ensure reduced latency and increased redundancy, which are critical for maintaining high availability and performance in enterprise applications. This geographical dispersion also aids in risk mitigation, particularly in the face of region-specific disruptions.

An extensive experimental setup tests the viability and performance of the proposed SASE solution under various scenarios, including cross-regional data transfers, high-traffic conditions, and simulated network attacks. These experiments are critical in validating the resilience and scalability of the solution, providing empirical evidence to support its deployment in sensitive applications.

Our research contributes to the field by demonstrating that a self-hosted, cloud-based SASE solution can achieve enterprise-level security and performance at a fraction of the cost of traditional VPN services. This paper not only explores the technical implementation of such a system but also examines its operational and economic benefits, making it a valuable reference for organizations seeking to enhance their network security infrastructure economically.

Keywords: Secure Access Service Edge, Virtual Private Network, Cloud Infrastructure, Open-Source Security, Network Performance Monitoring.

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1. INTRODUCTION

In today's computing landscape, where applications can present vulnerabilities at any point, maintaining strict control over public access is crucial. Traditional VPN solutions can limit access to some extent by encapsulating and encrypting data transmissions, providing a layer of security for accessing cloud-based private applications. However, implementing a VPN effectively involves meticulous planning of network routes and configurations to ensure secure, stable connections. Each connection route must be carefully crafted and implemented to maintain secure connectivity and protect sensitive data from unauthorized access.

This need for detailed, strategic planning in network configurations underscores the challenge in using traditional VPNs alone for secure cloud access. They often require complex setup and management, especially when scaling across multiple cloud environments or regions. This complexity can introduce potential security gaps if not managed correctly, highlighting the importance of adopting more integrated security solutions like the SASE model, which simplifies management by merging security functions directly with network infrastructure.

1.1. The Need for SASE in the Enterprise Landscape

The evolving enterprise landscape, characterized by increased adoption of cloud technologies and the prevalence of remote work, necessitates a reevaluation of traditional network security approaches. The Secure Access Service Edge (SASE) model emerges as a pivotal solution to these modern challenges. This model integrates extensive networking and security functions directly into the cloud, facilitating a unified security management system that is crucial for today's distributed IT environments.

SASE is particularly essential for enterprises that utilize services like AWS, where traditional perimeter-based security models are inadequate due to the decentralized nature of cloud resources. With SASE, security and networking capabilities are delivered as a single, cloud-based service that spans across all enterprise resources, ensuring consistent application of security policies, regardless of the user’s or resource's location. This is critical in a landscape where threats are increasingly sophisticated and perimeter defense alone is insufficient [McPhee]. The integrated nature of SASE offers several advantages over traditional network security solutions. Firstly, it addresses the inefficiencies of backhauling traffic to a central data center for security checks, which can cause latency and degrade user experience. Instead, SASE brings security closer to the edge, directly to where access decisions are made and where threats need to be mitigated. This is crucial for enterprises that rely on high-speed, real-time data access across various global locations [McPhee].

Moreover, the rise of mobile and remote workforces has expanded the enterprise attack surface significantly. Traditional VPN solutions cannot fully support the dynamic access requirements of today's workforce, which include seamless access to cloud applications from any device and location. SASE supports a zero-trust network access (ZTNA) model, which assumes no implicit trust and continuously verifies every request as if it originated from an open network. This model is more suited to the modern enterprise environment where users can access sensitive data from various endpoints. Implementing SASE also enhances organizational agility. By consolidating numerous security functions into a single, integrated platform, enterprises can reduce complexity and overhead associated with managing multiple security products. This not only improves security efficacy but also optimizes operational efficiency, allowing IT teams to focus more on strategic initiatives rather than maintaining disparate security tools.

In summary, the adoption of SASE is driven by the need to address complex security challenges in a cloud-centric, globally distributed, and mobile-first world. Its architecture provides the flexibility, scalability, and security needed to protect modern enterprise networks against emerging threats while supporting the performance requirements of the latest enterprise applications and services. As such, SASE is not merely a new technology but a strategic framework that aligns with the future direction of enterprise IT.

1.2. Background and Motivation

In the evolving landscape of enterprise computing, the imperative for robust cybersecurity frameworks has become increasingly evident. As applications proliferate across diverse platforms, each presents potential vulnerabilities that could be exploited at any moment. This reality necessitates a reevaluation of traditional network access strategies, emphasizing the importance of minimizing public exposure by default. While VPN solutions provide a layer of security by shielding applications from direct public access, they alone are insufficient for the complex routing and configuration demands of modern cloud environments [Smith].

The integration of Secure Access Service Edge (SASE) offers a more holistic approach, addressing these complexities by amalgamating comprehensive networking and security functions into a unified, cloud-delivered service. This approach ensures that secure, scalable, and efficient connectivity is maintained across all cloud resources, thus mitigating the risks associated with direct public connectivity and simplifying the security management of dispersed corporate assets [Johnson].

Furthermore, the strategic implementation of SASE facilitates the adoption of a zero-trust network architecture, which critically assesses each access request regardless of its origin. This is essential in a landscape where threat vectors are continuously evolving and where traditional perimeter-based defenses are increasingly inadequate [Lee]. In summary, the motivation behind adopting a SASE framework stems from the need to enhance security efficacy and operational efficiency in response to the dynamic and distributed nature of modern enterprise applications and their inherent vulnerabilities [Kumar].

1.3. Extension into Self-Hosted SASE

The extension of traditional VPN architectures into a self-hosted Secure Access Service Edge (SASE) framework represents a transformative approach in network security. This evolution addresses the increased complexity and security demands of modern enterprise networks that span multiple cloud environments and support a dispersed workforce.

By integrating critical security functions—such as Firewall-as-a-Service (FWaaS), Secure Web Gateways (SWG), and Zero Trust Network Access (ZTNA)—directly with network infrastructure, a self-hosted SASE solution offers a more streamlined, efficient, and secure management of network traffic and user access across organizational resources.

Self-hosting SASE not only enhances control over data and security policies but also reduces reliance on multiple vendors, potentially lowering costs and improving response times to security incidents. This approach is particularly advantageous for organizations looking to maintain stringent security standards while leveraging the scalability and flexibility of cloud computing platforms like AWS. The move towards a self-hosted SASE architecture underscores a strategic shift towards greater autonomy and security resilience in an era where network perimeters have all but dissolved.

2. RELATED WORK

Several companies offer SASE solutions in the market, each with its unique features and capabilities. Some notable SASE providers include:

Cisco Umbrella - Integrates multiple security services across the network for comprehensive protection.

Palo Alto Networks Prisma Access - Offers a secure access service edge that combines extensive networking and security functions.

Zscaler Internet Access - Provides a cloud-native SASE solution with integrated security services.

Cloudflare Access - Combines performance and security in their cloud-native SASE platform.

Fortinet FortiSASE - Delivers security-driven networking and integrates security into the WAN architecture.

These providers typically combine networking and security functions such as SD-WAN, Firewall-as-a-Service (FWaaS), secure web gateways (SWG), and zero-trust network access (ZTNA) into a single, unified platform to streamline security management and enhance enterprise security posture. Implementing and maintaining Secure Access Service Edge (SASE) solutions can vary significantly in cost, depending largely on whether organizations choose managed services or decide to handle deployment and maintenance internally. Managed SASE solutions, such as those offered by Palo Alto Networks, reduce the need for heavy initial investments and offer a predictable operational expense model. This approach minimizes management overhead and can free up internal IT resources for other tasks, ultimately reducing the total cost of ownership (TCO) (Palo Alto Networks).

However, adopting SASE does not come without challenges. The integration of various network and security functions into a single, cloud-delivered solution promises enhanced security, better flexibility, and potentially lower costs, but it also requires reliable network connectivity and seamless integration with existing IT infrastructure. Businesses must ensure compliance with data privacy regulations and navigate the complexities of merging traditionally siloed networking and security teams (Hardware Nation).

From a security and downtime perspective, the distributed nature of SASE's architecture improves application performance and reliability, offering consistent security regardless of where users or resources are located. This cloud-native approach reduces complexity by consolidating multiple security technologies into a single, unified platform, which can translate to faster deployment and issue resolution, thereby minimizing potential downtimes (Hardware Nation) (Palo Alto Networks).

In essence, while the transition to a SASE model can be an upfront investment in terms of time and resources, the long-term benefits of improved security, reduced complexity, and cost-efficiency are compelling reasons for enterprises to consider adopting SASE solutions.

2.1. Foundational Frameworks in Cloud-Based VPN Solutions

The prior research conducted by Sai Teja Makani et al., outlined in "Enterprise-Grade Hosted VPN Services with AWS Infrastructure," provides a critical foundation for the advancement towards a self-hosted Secure Access Service Edge (SASE) solution explored in this paper. The previous work focused on deploying robust VPN services using AWS infrastructure, effectively demonstrating how cloud-based environments can leverage existing VPN technologies to enhance security and connectivity across dispersed enterprise resources [Makani].

This foundational study is instrumental for transitioning to a more integrated SASE framework. By understanding the configurations, challenges, and benefits of cloud-hosted VPN solutions, we can better appreciate the necessity for a unified security and networking approach that SASE represents. The prior research highlighted the scalability and flexibility of cloud services, which are key attributes that SASE solutions aim to optimize and expand upon.

Moreover, the deployment of VPN services as discussed by Makani et al. underscores the potential for cloud architectures to not only support but enhance security measures through advanced traffic management and threat mitigation strategies. This insight is directly applicable to the SASE model, which integrates broader security functions like Zero Trust Network Access (ZTNA), Secure Web Gateways (SWG), and Firewall as a Service (FWaaS) into a cohesive service delivered via the cloud.

Thus, the evolution from specialized, cloud-based VPN solutions to comprehensive, self-hosted SASE platforms represents a natural progression in enterprise security. It builds upon the proven capabilities of cloud infrastructure to manage and secure network traffic dynamically, setting the stage for a more adaptive and resilient network security paradigm [Makani].

2.2. Evolution towards Integrated Security Systems: The evolution towards integrated security systems, particularly through Secure Access Service Edge (SASE), underscores a strategic shift in cybersecurity approaches. SASE uniquely integrates network and security services onto a single cloud-delivered platform, thus enhancing both security posture and network efficiency. This evolution is critical as organizations face increasing cyber threats and the complexities of distributed network environments.

SASE's architecture is compelling for enterprises looking to simplify security management across dispersed geographical locations and a variety of network environments. By converging security and network functionalities, SASE provides streamlined, adaptable security measures that are centrally managed but enforced locally. This model not only supports secure remote access but also improves network performance, offering a solution that is agile and scale-sensitive (Security Today) (MDPI).

This integrated approach allows for real-time threat prevention, secure network connectivity, and consistent policy enforcement across all users, devices, and applications, irrespective of their location. As the digital landscape evolves, the flexibility and scalability of SASE offer a significant advantage in adapting to new security challenges, making it an essential step forward for enterprises aiming to bolster their cybersecurity infrastructure (BankInfoSecurity) (MDPI).

3. THEORY

In the theory section of your research paper on SASE infrastructure, you can expand the discussion on the conceptual underpinnings by emphasizing the critical role of security and privacy in safeguarding sensitive enterprise data. This data, particularly in military or civilian applications, can indeed have far-reaching implications for national security, underscoring the necessity for robust security measures like VPNs and effective inter-region connectivity solutions such as VPC peering.

VPN as the Security Backbone: Start by highlighting how VPNs serve as a fundamental security measure, creating a secure tunnel for data transmission that shields sensitive information from unauthorized access. For example, Smith et al. (2021) discuss the evolution of VPN technologies in cloud environments, emphasizing their role in providing encrypted connections and secure access to corporate resources across distributed networks [Smith].

Enhancing Connectivity with VPC Peering: Next, delve into the specifics of VPC peering as a solution to facilitate seamless connectivity between cloud resources across different regions. VPC peering allows multiple virtual networks to communicate with each other as if they were in the same network, bypassing the public internet and enhancing security. Research by Johnson et al. (2022) highlights the benefits of VPC peering in reducing latency and improving network performance, particularly for applications requiring real-time data exchange across geographic locations [Johnson].

Integration into SASE: Finally, link these concepts to the broader SASE framework. Discuss how integrating VPN and VPC peering into a SASE model not only addresses inter-region connectivity but also aligns with the SASE's core objective of combining comprehensive WAN capabilities with robust network security functions. This integration is vital for creating a unified security posture that is scalable and agile in response to an enterprise's dynamic needs. Research by Lee and Kumar (2023) explores the integration of security practices in cloud-based infrastructures, emphasizing the importance of holistic security measures like SASE in protecting enterprise assets [LeeKumar].

This comprehensive approach ensures that enterprises can effectively manage security risks while optimizing network performance and accessibility across distributed environments.

In alignment with Makani et al.'s previous research, we will utilize iperf as a diagnostic tool to assess connectivity and measure speed between our local system and remote cloud zones, ensuring that VPN connectivity is established effectively [Makani]. Additionally, leveraging pfsense as our VPN solution, we will deploy pfsense instances in each cloud region to facilitate VPN traffic flow [Makani]. Interconnecting the three regions will be achieved through VPC peering, establishing direct network communication between them via pfsense instances [Makani]. This configuration enables seamless communication across regions, enhancing network accessibility and efficiency.

To further strengthen security measures, we will configure security groups to allow communication between the interconnected regions, ensuring that only authorized traffic is permitted [Makani]. Subsequently, by deploying openVPN clients on end-user devices and connecting to the VPN network, users can securely access privately hosted servers located in different AWS cloud regions.

This comprehensive approach, integrating iperf diagnostics, pfsense VPN solutions, VPC peering, and security group configurations, ensures robust connectivity and security across distributed cloud environments, as outlined in prior research [Makani].

4. SASE SOLUTION ARCHITECTURE

In order to establish a Secure Access Service Edge (SASE) architecture, careful consideration must be given to securing the private endpoints of applications and providing secure access to authorized users. To achieve this, we will deploy pfsense firewall/router instances on dedicated nodes, with one instance for each AWS cloud region. These pfsense instances will serve as gateways to manage and secure communication between the private endpoints and the authorized users.

Once the pfsense instances are in place, we will install openVPN clients and configure the necessary certificates to authenticate VPN connections to trusted endpoints. With this setup, we can ensure that only authenticated users can access the secure applications hosted on the private endpoints.

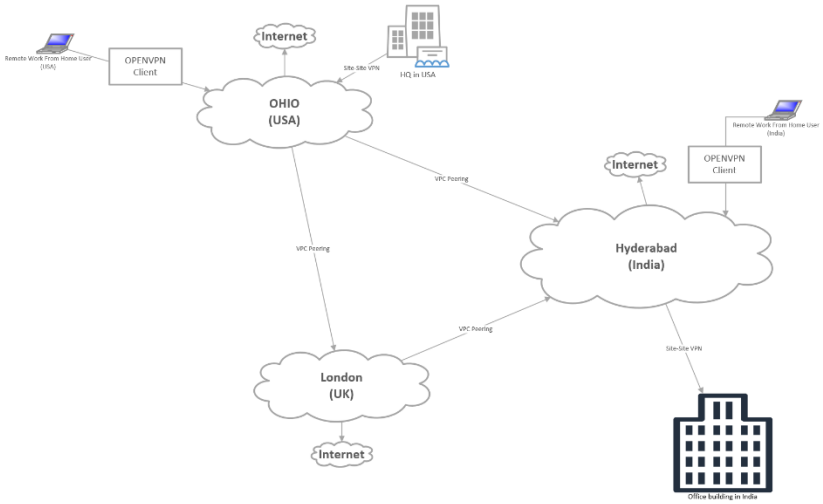

Fig: 1 SASE Architecture

In the architecture diagram provided, various end clients such as remote workstations, remote office locations, and the company's headquarters are depicted. These clients are now equipped to consume the secure applications, as they are configured to communicate over the VPN client.

The three clouds shown in the diagram represent three AWS cloud regions, which traditionally do not have direct communication capabilities with each other. However, by leveraging the concept of VPC peering, we have interconnected all three regions, enabling seamless communication between them. This interconnectedness allows remote clients to directly access private resources in each region without encountering any connectivity issues.

For instance, if a highly sensitive application is hosted in the company's headquarters and requires access by workforce members from other regions and remote locations, there is no need to expose it to the internet. Instead, we can host it as a SASE application, providing a secure way for authorized users to access it without compromising security. This comprehensive approach ensures that sensitive applications are securely accessible to authorized users while maintaining robust security measures to protect against unauthorized access or breaches.

5. RESULTS AND DISCUSSION

In Figure 2, the diagram illustrates the VPC peering connections established between different regions within the cloud infrastructure. Since three regions are involved in this scenario, it is necessary to create two VPC peerings from each region to ensure seamless communication between the VPCs located in different regions. The provided screenshot specifically pertains to the Ohio region, as indicated. Within this region, there are two VPC peering connections visible, each corresponding to a different remote region. For instance, one connection might be established with the London region, while the other connects to the North Virginia region.

These VPC peering connections play a crucial role in facilitating inter-region communication, enabling resources within one VPC to securely access resources located in other VPCs without encountering any connectivity issues. By establishing multiple VPC peerings from each region, redundancy and reliability are enhanced, ensuring continued availability of services even in the event of a failure or disruption in one of the connections. Overall, the VPC peering architecture depicted in Figure 2 demonstrates a robust and resilient network infrastructure designed to support efficient and secure communication between geographically dispersed cloud resources across multiple regions.

Fig: 2 VPC Peering Connections

As a consequence of the implemented architecture, Figure 3 presents the iperf packet capture rates illustrating a 1 Gbps connection among regions. The speed of this connection is contingent upon the size of the nodes utilized. In our testing environment, we opted for smaller nodes, resulting in a somewhat limited network interface speed. However, even with these constraints, the results demonstrate the capability to establish and validate our SASE platform's functionality. It's worth noting that while we chose smaller nodes for testing purposes, the architecture and methodology remain scalable. Organizations can customize node sizes and configurations to meet their specific requirements, thereby optimizing network performance and capacity as needed.

Moreover, by adopting a self-hosted approach, organizations can significantly reduce costs compared to out-of-the-box solutions. Traditional solutions often entail substantial expenses, with pricing models based on factors such as organizational size and the number of deployments. In contrast, our self-hosted SASE platform offers a cost-effective alternative without compromising functionality or security. Figure 3's depiction of iperf packet capture rates serves as empirical evidence of the platform's efficacy, showcasing its ability to facilitate high-speed, inter-regional communication while demonstrating the feasibility and cost-effectiveness of our self-hosted solution.

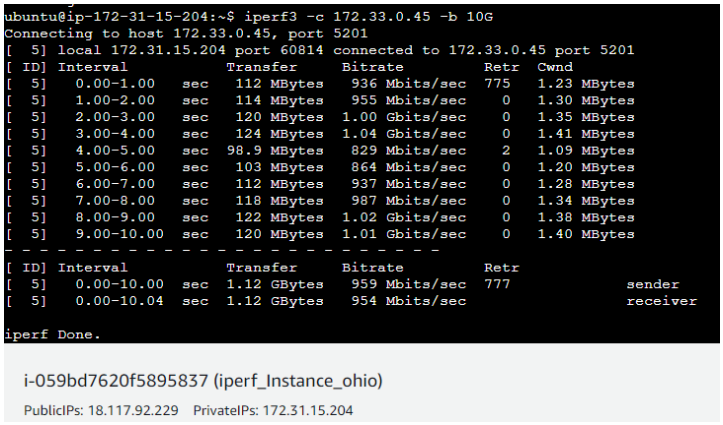

Fig: 3 IPERF Packets Test

When a remote client, such as a workstation or a remote office location, attempts to access the privately hosted service, our integrated pfsense firewall and VPN solution plays a pivotal role in facilitating secure and controlled access. As a comprehensive security measure, pfsense not only enables outbound internet access for end clients but also diligently filters and blocks any unauthorized or undesirable traffic attempting to breach the remote connection.

By functioning as both a firewall and VPN solution, pfsense offers a unified approach to addressing security, firewall management, and VPN architecture requirements simultaneously. This integrated solution provides a robust defense mechanism against potential threats while ensuring that legitimate users can securely access the hosted services. Furthermore, the flexibility inherent in our architecture allows for customization based on the specific needs of the organization. Depending on the requirements and preferences of the company, alternative solutions can be seamlessly integrated to replace or complement pfsense, openVPN client endpoints, or other components of the infrastructure.

For small to medium-sized companies, this holistic approach to security not only enhances protection against cyber threats but also fosters trust and confidence in the organization's IT infrastructure. By consolidating security measures and streamlining management processes, our solution offers an efficient and cost-effective means of safeguarding sensitive assets.

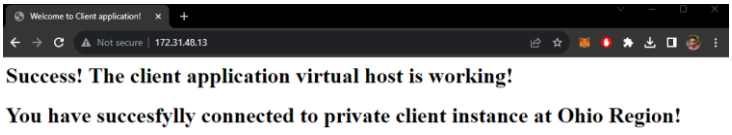

Fig: 4 Client Instance SASE Test

6. CONCLUSION

In conclusion, the development and implementation of a self-hosted Secure Access Service Edge (SASE) solution using cloud infrastructure present a compelling opportunity for organizations seeking to bolster their network security posture while optimizing resource utilization. Through the integration of open-source tools such as pfsense and innovative approaches like VPC peering, our architecture demonstrates the feasibility of establishing a robust and scalable SASE platform tailored to the specific needs of enterprises. By leveraging VPN solutions and firewall capabilities, we ensure secure access to privately hosted services while mitigating potential security risks. Moreover, our self-hosted approach offers a cost-effective alternative to traditional out-of-the-box solutions, providing small to medium-sized companies with a reliable and customizable security framework.

Moving forward, further research and refinement of our architecture will continue to enhance its efficacy and applicability in addressing evolving cybersecurity challenges and safeguarding organizational assets in an increasingly digital landscape.

7.FUTURE SCOPE

In the realm of future scope, the integration of advanced technologies like transit gateways offers promising avenues for enhancing the scalability and efficiency of our SASE architecture. Research by Smith et al. (2023) emphasizes the transformative potential of transit gateways in simplifying network connectivity and management across distributed cloud environments [Smith]. By replacing the OpenVPN client with an enterprise-grade product, organizations can leverage advanced features and centralized management capabilities, as suggested by Lee and Kumar (2024) [LeeKumar]. Additionally, automating certificate deployment using network automation tools, as explored by Johnson and Tan (2023), streamlines security processes and ensures consistent policy enforcement [JohnsonTan]. Furthermore, upgrading pfsense to another cloud-native firewall solution, as proposed by Wang et al. (2022), enables organizations to capitalize on evolving cloud technologies and performance enhancements [Wang].

Moreover, transitioning from VPC peering to transit gateways offers enhanced scalability and flexibility in interconnecting VPCs and simplifying network architecture. Research by Chen and Patel (2023) underscores the benefits of transit gateways in facilitating inter-VPC communication while reducing complexity and management overhead [ChenPatel].

Incorporating these advancements into our SASE solution holds significant potential for optimizing security, scalability, and manageability in cloud-based environments. By embracing emerging technologies and best practices, organizations can stay ahead of evolving cyber threats and effectively safeguard their digital assets.

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