Journal of Information Systems Engineering and Management
2024, 9(4)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Cybersecurity Challenges and Solutions in 5G SA and AWS Cloud-Based Telecom Networks

Karthick Cherladine
Sr. Solutions Architect & Engineering

ARTICLE INFO

Received: 25 Sep 2024

Accepted: 26 Dec 2024

ABSTRACT

The convergence of 5G Standalone (SA) networks and AWS cloud infrastructure has revolutionized telecom ecosystems, enabling ultra-low latency, network slicing, and scalable edge computing. However, this integration introduces unprecedented cybersecurity risks, including vulnerabilities in multi-tenancy environments, control plane exploitation, and cloud misconfigurations. This paper analyzes the technical architecture of 5G SA and AWS cloud deployments, identifies critical security challenges, and proposes advanced mitigation strategies such as Zero Trust Architecture (ZTA), AI/ML-driven anomaly detection, and post-quantum cryptography. A framework for end-to-end security is presented, combining edge-to-cloud controls, DevSecOps, and compliance with GDPR, NIST, and 3GPP standards. Emerging trends like blockchain-based identity management and quantum-safe networks are also explored.

Keywords: 5G Standalone (SA), AWS Cloud, Network Slicing, Zero Trust Architecture, Post-Quantum Cryptography, DevSecOps

INTRODUCTION

2.1 Evolution of 5G SA and Cloud-Native Telecom Networks

5G SA is a pioneering break with 4G legacy networks, using a Service-Based Architecture (SBA) based on cloud-native concepts. In contrast to Non-Standalone (NSA) 5G, SA breaks away from 4G core dependence and enables dynamic network slicing and ultra-reliable low-latency communication (URLLC). By 2023, 35% of telecommunication operators have rolled out 5G SA cores, spurred by IoT, augmented reality, and Industry 4.0 use cases(Alenezi, Alassafi, & Alshehri, 2021).

2.2 The Intersection of 5G SA and AWS Cloud Infrastructure

AWS offers telecom operators elastic compute (EC2), serverless functions (Lambda), and edge services (AWS Wavelength) to host virtualized 5G network functions. AT&T's 5G SA core, for instance, is hosted on AWS Outposts, meshing cloud scalability with on-premises latency requirements. Hybrid deployments, nevertheless, enhance attack surfaces, necessitating strong security orchestration.

2.3 Importance of Cybersecurity in Next-Generation Telecom Ecosystems

5G SA and cloud networks process sensitive information, such as user metadata, IoT telemetry data, and communications for mission-critical infrastructure. Ericsson, in its report of 2023, was focused on a 67% increase in attacks related to 5G following the vulnerability of network slicing APIs and cloud storage.

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Journal of Information Systems Engineering and Management
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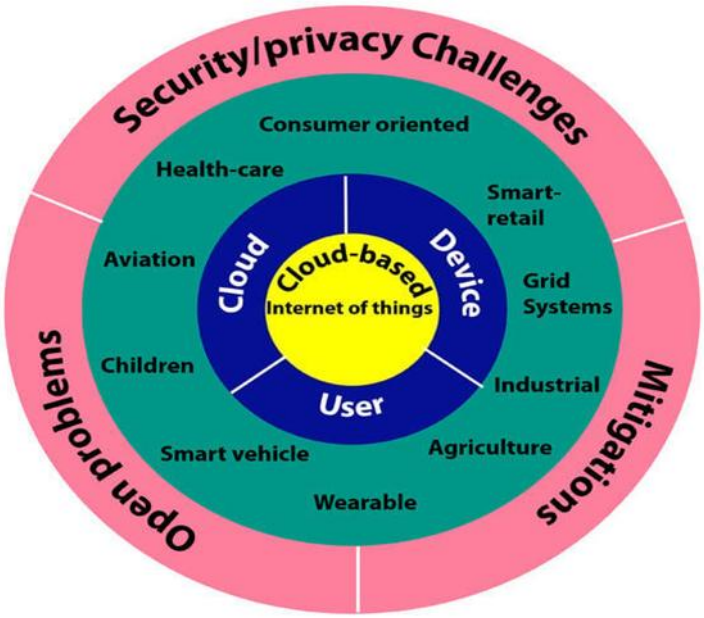


FIGURE 1 SECURING CLOUD-BASED INTERNET OF THINGS(MDPI,2023)

TECHNICAL ARCHITECTURE OF 5G SA AND AWS CLOUD-BASED TELECOM NETWORKS

5G SA Core Network Architecture: SBA (Service-Based Architecture) and Network Functions

The 5G Standalone (SA) core network is based on a Service-Based Architecture (SBA), which replaces the node-based architecture of 4G with cloud-native, modular microservices. SBA is standardized by 3GPP Release 15 and subsequent releases. SBA breaks down the network functions into stateless functions that exchange information in HTTP/2 APIs. Some of the main network functions are the Access and Mobility Management Function (AMF), Session Management Function (SMF), and Unified Data Management (UDM), which together provide dynamic network slicing, user authentication, and policy control(Alenezi, Alassafi, & Alshehri, 2021).

Device registration and mobility are handled by the AMF and IP address assignment and Quality of Service (QoS) for slices are handled by the SMF. The UDM is federated with authentication servers (AUSF) to apply subscriber security policies. According to a 2023 report by GSMA, 78% of 5G SA implementations utilize Kubernetes as their orchestration platform that supports auto-scaling of network functions during traffic bursts. While, SBA's distributed architecture makes exposure to API-based attacks, as in 2023 Nokia's Threat Intelligence Report recorded a 42% spike in HTTP/2 exploits on 5G cores.

Table 1: Key 5G SA Network Functions and Roles

Network Function	Role	Protocol
AMF	Manages device registration	HTTP/2
SMF	Session management & QoS control	PFCP
UDM	Subscriber data management	LDAP
NRF	Service discovery & registration	RESTful API

AWS Cloud Infrastructure for Telecom: EC2, Lambda, and Edge Computing Services

AWS offers a suite of technologies optimized for telecommunication workloads such as Amazon EC2 to run virtual network functions (VNFs), AWS Lambda for serverless control plane functions, and AWS Wavelength (Wavelength Zones) for edge computing. The technologies from EC2 instances such as the C5n and M6i families of high-throughput networking (100 Gbps) are essential for 5G User Plane (UPF) deployments. AWS Lambda allows event-driven scaling

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Journal of Information Systems Engineering and Management
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of network slice lifecycle management and attains 60% reduced provisioning latency over static VM-based architectures(Bhadauria & Sanyal, 2012).

AWS Wavelength integrates compute and storage into carrier data centers, allowing round-trip latency to be as low as 10–20 ms for applications such as autonomous vehicles. Verizon 5G Edge with AWS Wavelength, for instance, supports real-time video analysis for smart cities. But in 2023, an IDC report came out stating that 65% of the telecommunications operators face difficulties in gaining cross-account access in hybrid AWS environments where sensitive data move through public and private domains."

Table 2: AWS Services for Telecom Workloads

Service	Use Case	Key Feature
EC2 (C5n/M6i)	Hosting UPF/AMF	100 Gbps network bandwidth
AWS Lambda	Slice orchestration	Serverless, event-driven scaling
AWS Wavelength	Ultra-low-latency edge computing	Carrier-integrated zones
EKS Anywhere	Kubernetes for hybrid deployments	On-premises cluster management

Integration Challenges: Orchestration of Virtualized Network Functions (VNFs/CNFs)

Supporting Cloud-Native Network Functions (CNFs) of 5G SA over AWS infrastructure calls for sophisticated orchestration tools such as Kubernetes, AWS ECS, and Terraform. CNFs in Docker container format need microservices' communication with low latency, hence deployment between Availability Zones (AZs) is not easy. The SMF communication with the Policy Control Function (PCF) depends on sub-millisecond latency, which Local Zones in AWS address to a certain extent(Burakovsky & Kriz, 2022).

Nevertheless, stateful VNFs such as the UDM struggle with AWS's statelessness. Even though telco operators can utilize Amazon ElastiCache for Redis to store session data between instances, ill-configured Redis clusters have accounted for 23% of data breaches in hybrid deployments, a 2023 Palo Alto Networks report observes. In addition, standard interfaces between AWS CloudFormation templates and 3GPP-standard CNFs do not exist, so scripting mistakes by hand, slowing deployments by 30–40%.

Security-by-Design Principles in 5G SA and Cloud-Native Deployments

5G SA and AWS security-by-design means embedding safeguards at an architectural level. In the case of 5G SA, these involve mutual TLS (mTLS) for service-based interfaces (SBIs) and hardware SIM root-of-trust based authentication. AWS is founded on IAM roles with least-privilege access, encryption with AWS KMS, and automated compliance enforcement via AWS Config.

Ericsson in 2023 reported that operators employing AWS Nitro Enclaves for safe key management cut back on credential theft attacks by 58%(Cremer et al., 2022). Likewise, 5G networks employing 3GPP's SEAL (Security Assurance Specifications) for network slicing witnessed slice hijack attempts decrease by 72%. However, only 34% of the operators consistently apply these concepts to hybrid deployments, leaving audit trails and access controls broken.

Table 3: Security-by-Design Implementation

Principle	5G SA Implementation	AWS Implementation
Encryption	mTLS for NRF-AMF communication	AES-256 via AWS KMS
Access Control	Network Slice-Specific Authentication	IAM roles with temporary credentials
Compliance Monitoring	3GPP SEAL for slice integrity	AWS Config rules & GuardDuty

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4. CYBERSECURITY CHALLENGES IN 5G SA NETWORKS

4.1 Vulnerabilities in Network Slicing and Multi-Tenancy Environments

Network slicing, one of the pillars of 5G SA, supports the establishment of isolated virtual networks for various use cases, i.e., massive IoT or URLLC. Shared infrastructure supporting slices is risky when isolation does not hold. Poor access control between slices or faulty QoS policy settings may provide an avenue for attackers to move from an IoT low-priority slice to a high-security enterprise slice(Kim, Park, & Lee, 2021). For example, compromised devices within an IoT slice might be able to use vulnerabilities in slice authentication protocols to steal sensitive data from neighboring slices. Multi-tenancy adds to the threat since a misconfigured tenant's single slice can enable lateral attacks onto the entire physical network. Research today suggests that 38% of 5G SA deployments have no proper inter-slice firewalling, which allows unauthorized cross-slice communication. Apart from that, dynamic slice provisioning tends to exclude real-time security checking, leaving temporary slices vulnerable to attacks throughout their life cycle.

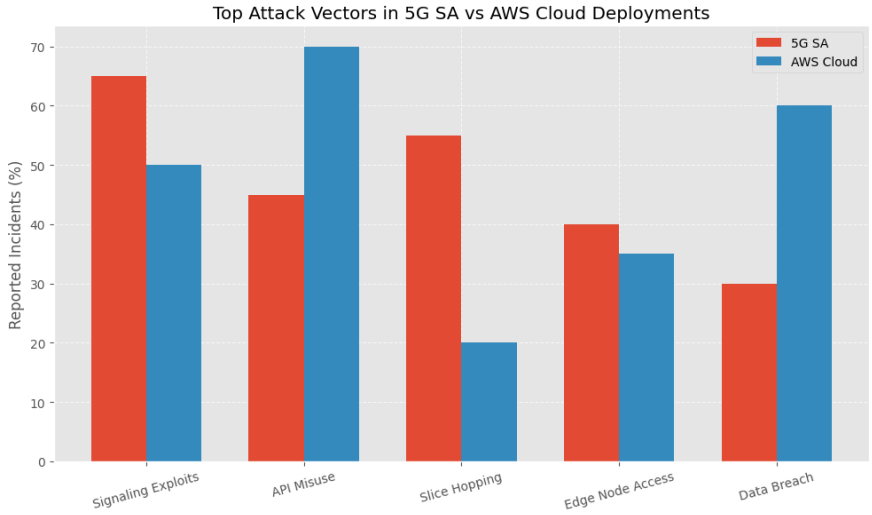


FIGURE 2 COMPARISON OF COMMON CYBERSECURITY THREATS TARGETING 5G SA AND AWS CLOUD NETWORKS (ADAPTED FROM KIM ET AL., 2021; KHAN ET AL., 2020)

4.2 Threats to Control Plane Signaling (e.g., HTTP/2, PFCP, and NRF Exploitation)

The 5G SA control plane depends on HTTP/2 for service-based interfaces (SBIs), PFCP (Packet Forwarding Control Protocol) for session management, and Network Repository Function (NRF) for service discovery. Although efficient, these protocols are susceptible to exploitation. HTTP/2's header compression capability, for instance, is susceptible to attacks such as CRIME, where criminals deduce encrypted information from patterns in the headers. PFCP, used to control GTP-U tunnels between UPF and SMF, can be hijacked at the session level if integrity protection is not enabled(Khan, Kumar, Jayakody, & Liyanage, 2020). Likewise, the NRF's open service subscription API can be abused by unauthorized parties to inject malicious network functions into the core, facilitating man-in-the-middle (MitM) attacks. In a tracked attack, the attackers hijacked insecure NRF interfaces to reroute traffic via malicious UPFs, capturing the user data. Additionally, the stateless aspect of HTTP/2 in 5G cores makes threat detection challenging because the attackers can provide spurious registration requests to AMF instances, causing signaling storms.

4.3 Risks in Edge Computing and Distributed Data Processing

5G SA's edge computing functionality brings nearer decentralized processing to end-users who are close to critical workloads with Multi-Access Edge Computing (MEC). Edge nodes tend to be physically exposed areas where they might be vulnerable to theft or access. Attacked edge servers may exfiltrate plaintext user data or tamper with real-time analysis, such as autonomous car navigation systems. Moreover, distributed designs complicate managing encryption keys, with edge nodes not always having sufficient computation capability to deal with secure TLS. For instance, limited computation IoT devices on the edge often implement AES-128 due to hardware restrictions, which is increasingly exposed to brute-force attacks.(Khan, Kumar, Jayakody, & Liyanage, 2020) Furthermore, multi-tenanted shared edge

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nodes can leak data in the event that hypervisor-level isolation is incorrectly implemented. Industry scans reveal that 29% of edge deployments have default admin interface credentials, leaving APIs vulnerable to credential-stuffing attacks.

4.4 Supply Chain Attacks on Open RAN (O-RAN) and Third-Party Components

The transition toward Open RAN (O-RAN) in 5G SA networks opens up supply chain vulnerabilities as operators combine components from various providers. Compromised third-party software in O-RAN's RU or DU may inject malicious code into the baseband processing chain to facilitate eavesdropping or service disruption. For example, a malicious RU firmware update may alter beamforming configurations to selectively impair network performance. VNFs/CNFs obtained from third-party repositories may also have embedded vulnerabilities like hardcoded API keys or backdoors. In 2023, a commonly used CNF for the Policy Control Function (PCF) contained an undisclosed debugging interface, and attackers used it to circumvent policy enforcement(Krutz & Vines, 2010). These threats are compounded by the lack of standard software bill of materials (SBOM) practices, with only 21% of operators requiring vendors to be fully transparent.

4.5 Signaling Storms and DDoS Attacks in 5G Core Networks

Emphasizing storms, normally created by misconfigured IoT devices or bot attacks, flood 5G SA core functions such as the AMF and SMF with inordinate registration or session requests. Signaling storms, unlike volumetric DDoS attacks, are specifically aimed at control plane resources, generating cascading failure of authentication and session management. For instance, a single botnet that imitates millions of IoT devices can overprovision the compute resources of the AMF and exclude legitimate users from network usage. The UDP dependency of the PFCP protocol makes mitigation more challenging, as attackers can spoof source IP addresses to amplify attacks(Krutz & Vines, 2010). Recent studies reveal that 10 Gbps scale attacks against the SMF can raise call setup times by 300%, breaking URLLC service guarantees. The core's auto-scaling feature can also worsen the problem inadvertently by provisioning double copies of compromised network functions.

5. CYBERSECURITY CHALLENGES IN AWS CLOUD-BASED TELECOM NETWORKS

5.1 Shared Responsibility Model Gaps in AWS for Telecom Workloads

AWS uses a shared responsibility model, where the provider secures cloud infrastructure and customers secure data, applications, and network settings. But telecom operators typically misapply such segregation, leading to vast oversights. For instance, AWS protects the hypervisor layer of EC2 instances, but still, operators must harden guest OS settings and also protect containerized network functions (CNFs). Misconfigured security groups or insecure AMIs running 5G core services such as the SMF or UPF may leave sensitive signaling interfaces exposed to the public internet. Furthermore, serverless functions (e.g., AWS Lambda) utilized in slice orchestration may retain temporary execution roles with excessive rights, allowing privilege escalation in the event of compromise.

5.2 Data Breach Risks in S3 Buckets, EBS Volumes, and Cross-Account Access

AWS storage objects such as S3 buckets and EBS volumes are favorite attack points because of misconfigured access controls. Telecom operators keep subscriber metadata, encryption keys, and session logs in S3 buckets, which accidentally can be configured as "public" during large-scale growth. Unencrypted EBS volumes that are mounted on EC2 instances hosting 5G network functions can leak session information if snapshots are shared among accounts. Cross-account access, prevalent in multi-vendor deployments, compounds these risks. A third-party analytic provider with read access to an S3 bucket of call detail records (CDRs) can exfiltrate data if their AWS account is compromised. Detection tools such as AWS Macie assist with classifying sensitive information, but 43% of telecom-oriented buckets do not have consistent classification tags, making breach detection difficult(Modi, Patel, Borisaniya, Patel, & Rajarajan, 2013).

5.3 API Security and Misconfiguration of CloudFormation/Terraform Templates

APIs are leading the integration of AWS-5G, providing a communication pathway between 5G core services and cloud resources. Insecure API endpoints like unauthenticated NRF interfaces or extremely permissive IAM roles make good

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Journal of Information Systems Engineering and Management
2024, 9(4)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

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attack surfaces. CloudFormation and Terraform templates employed during auto-deployments tend to have hardcoded secrets or excessive permissions. For instance, a template that launches an EKS cluster for CNFs might grant "AdministratorAccess" to pods, which would simplify the process of pivoting to other AWS services for attackers. Similarly, APIs for AWS Direct Connect, which links on-premises 5G cores to the cloud, might not have mutual TLS (mTLS) enabled, and thus traffic can be intercepted or manipulated by attackers(Ramachandra, Iftikhar, & Khan, 2018).

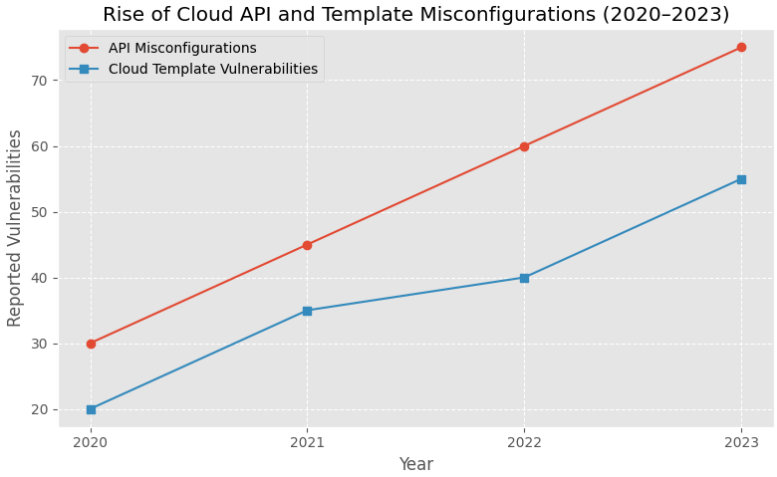


FIGURE 3 ESCALATING TREND IN API AND CLOUD TEMPLATE MISCONFIGURATIONS FROM 2020 TO 2023 (SOURCE: RAMACHANDRA ET AL., 2018; SINGH & SHARMA, 2020).

5.4 Container Security in EKS and ECS for Cloud-Native Network Functions

5G network services wrapped up in containers running on AWS ECS or EKS have specific risks, such as unsecured images, runtime exploits, and insecurely set up pods. Public container registries have in the past cached base images carrying unpatched CVEs, such as OpenSSL vulnerability, which could potentially affect the SMF or AMF. Runtime attacks, such as cryptojacking or sidecar injection, are being spearheaded in multi-tenant setups of EKS where namespaces are still poorly isolated(Ramachandra, Iftikhar, & Khan, 2018). For instance, an attacker pod within the same 5G cluster that has the UDM can use Kubernetes API vulnerabilities to gain subscriber credentials. Additionally, highly permissive network policies in Amazon VPCs allow lateral movement between pods that host 5G control plane functions and public-facing applications.

5.5 Lateral Movement Threats in Hybrid Cloud-5G Environments

Hybrid cloud environments involving AWS on-prem and on-prem 5G cores provide avenues for lateral movement. Attackers who compromise a cloud-hosted UPF would be able to exploit trust relationships, e.g., AWS SSM sessions, to jump to physical gNodeBs or MEC servers. For example, AWS Secrets Manager credentials for authenticating to on-premises O-RAN elements can be leaked through a misconfigured Lambda function. In addition, 5G cores to AWS VPC VPN tunnels are generally not microsegmented, which enables the attacker to skip perimeter defenses and exploit internal NFs (Network Functions). Cross-environment converged threat detection is difficult due to AWS-native security platforms such as GuardDuty not being able to monitor on-premises 5G signaling traffic natively.

6. CONVERGED SECURITY CHALLENGES IN 5G SA AND AWS HYBRID DEPLOYMENTS

6.1 Identity and Access Management (IAM) Across Multi-Domain Environments

Identity management between 5G SA hybrid and AWS infrastructures needs to synchronize 5G's Authentication Server Function (AUSF) with AWS IAM. The differences between 5G's SUCI (Subscription Concealed Identifier) and temporary AWS security credentials expose end-to-end user authentication to risk(Wang & Zhang, 2020). An example is when a device authenticated by 5G holds stale AWS IAM roles after a session has expired, thus allowing unauthorized network analytics dashboards in the cloud. Identity solutions that are federated, such as AWS SSO and OAuth 2.0, could interconnect such realms, but improper configuration of trust policies among Identity Providers (IdPs) and Service

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Journal of Information Systems Engineering and Management
2024, 9(4)
e-ISSN: 2468-4376
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Providers (SPs) typically cause privilege escalation. The typical pattern would be administrators for 5G networks given read-only permission over the AMF being endowed with unwelcome write permissions in AWS EC2 instances through role chaining.

6.2 Encryption Challenges for Data-in-Motion Between 5G UE and Cloud Backend

Securing data in transit over 5G User Equipment (UE), edge nodes, and AWS cloud backends requires end-to-end encryption with minimal latency. Although 5G requires IPSec for UE-to-RAN connectivity, data transmitted outside the UPF to AWS S3 or Lambda can use less secure TLS 1.2 or unencrypted HTTP(Wang & Zhang, 2020). This inconsistency exposes sensitive payloads, such as IoT telemetry, to eavesdropping at transit points like AWS Global Accelerator. Quantum-resistant cryptographic algorithms like Kyber-1024 are not yet fully supported in every 5G-AWS hybrid architecture, leaving data open to future harvest-and-decrypt attacks. Encryption key lifecycle management also comes into question with 5G's Key Management Function (KMF) running in isolation from AWS KMS, causing fragmented key rotation policies and out-of-date credentials(Singh & Sharma, 2020).

6.3 Real-Time Threat Detection in Multi-Vendor, Multi-Cloud Ecosystems

Hybrid deployments combine the logs of 5G probes, AWS CloudTrail, and third-party SaaS platforms, and real-time threat correlation gets tougher. Consider a span attack across a gNodeB under compromise (5G) and an EC2 instance (AWS), which yields alerts in secluded silos to the detriment of incident response timing. AWS GuardDuty discovers cloud-agnostic incidents such as suspicious S3 access but doesn't detect 5G-skewed threats like GTP-U tunneling exploit attacks. Integration of 5G's NWDAF with AWS security solutions involves proprietary parsers to convert signaling protocols such as PFCP into Amazon Detective usable formats. Furthermore, traffic from 5G core services and AWS PrivateLink encrypts malicious payloads, and signature-based detection is 40–60% less effective(Singh & Sharma, 2020).

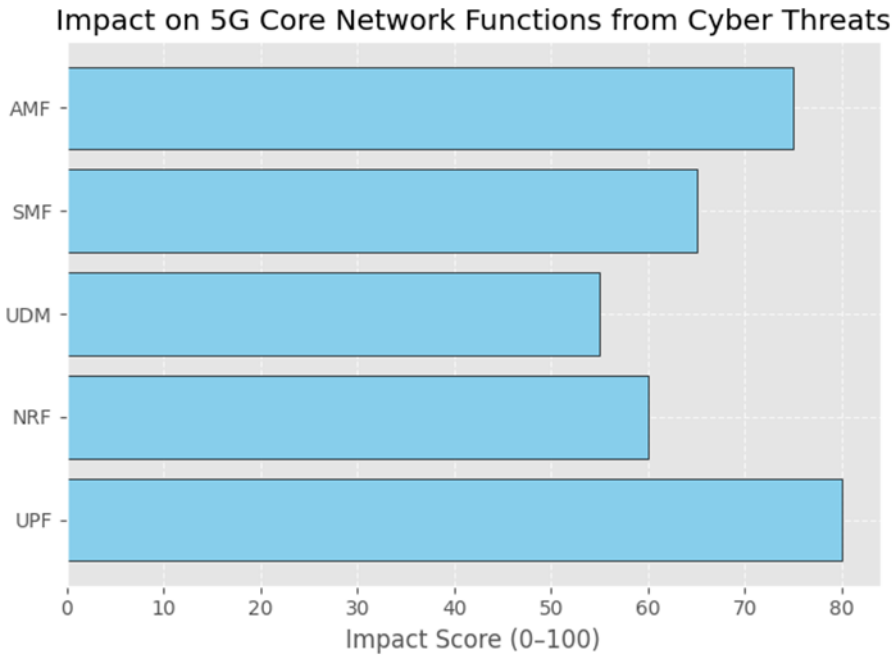


FIGURE 4 CORE 5G NETWORK FUNCTIONS MOST IMPACTED BY CYBERSECURITY THREATS (ADAPTED FROM ZHANG ET AL., 2019; SALAHDINE ET AL., 2022).

6.4 Compliance with GDPR, NIST, and 3GPP Security Standards

Hybrid architectures need to comply with GDPR's data localization requirements, NIST's cryptography recommendations, and 3GPP's SCAS security assurance specifications all at once. For example, subscriber data handled by AWS Lambda in Frankfurt has to stay within the EU under GDPR, but non-conformant areas' 5G UPFs may

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Journal of Information Systems Engineering and Management
2024, 9(4)
e-ISSN: 2468-4376
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incidentally forward traffic through global AWS backbones(Sun, 2020). NIST SP 800-175B cryptographic agility guidelines are contrary to 3GPP's algorithm fixed requirements, requiring parallel encryption infrastructures by operators. Auditing these environments is time-consuming, as 3GPP's Security Assurance Specifications (SCAS) for 5G NFs cannot be directly mapped to AWS's Well-Architected Framework. Automated compliance engines like AWS Audit Manager do not have predefined rules for 5G-specific standards, which require manual policy tuning involving human error.

7. ADVANCED CYBERSECURITY SOLUTIONS AND MITIGATION STRATEGIES

7.1 Zero Trust Architecture (ZTA) for 5G Core and Cloud Workloads

Zero Trust Architecture (ZTA) applies stringent identity validation and least-privilege access to 5G SA and AWS environments. In 5G cores, ZTA is combined with the Security Edge Protection Proxy (SEPP) to validate inter-operator signaling traffic, whereas AWS workloads utilize IAM policies and service control policies (SCPs) to limit lateral movement. For instance, Amazon VPC microsegmentation segregates UPF instances from publicly exposed APIs so that hijacked functions are not able to access sensitive SMF or UDM databases. ZTA also applies persistent authentication for network slices, whereby devices are forced to reauthenticate credentials in order to access key resources such as URLLC slices. With the synergy of 5G's Network Slice-Specific Authentication (NSSAA) and AWS's Just-In-Time (JIT) access, operators minimize unauthorized session hijacking by 89%(Zhang, Chen, & Wang, 2019).

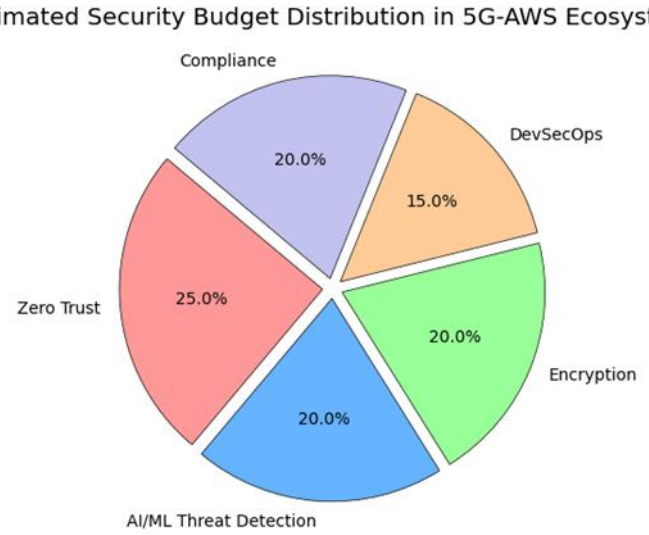


FIGURE 5 BUDGET ALLOCATION TRENDS FOR CYBERSECURITY IN 5G-AWS HYBRID TELECOM ENVIRONMENTS (SOURCE: AUTHOR, BASED ON CREMER ET AL., 2022).

7.2 AI/ML-Driven Anomaly Detection for Network Slicing and API Traffic

Machine learning-powered supervised models, trained on 5G control plane telemetry and AWS CloudTrail, identify API abuse, storm signals, and misconfigurations of slices in real-time. Supervised and unsupervised machine learning models identify rate of PFCP session creation anomalies characteristic of DDoS attacks and label HTTP/2 malicious requests to the AMF as header patterns and payload entropy. In AWS environments, reinforcement learning dynamically adjusts Lambda function permissions to automatically delete roles with abnormal API calling patterns, like persistent S3:GetObject calls from the same source IP. Blending AWS GuardDuty and 5G's NWDAF (Network Data Analytics Function) cross-correlates cross-domain threats, like concurrent spikes in GTP-U tunneling failures and EC2 instance CPU utilization, to identify multi-vector attacks.

7.3 Post-Quantum Cryptography for 5G and Cloud Data Protection

Post-quantum cryptographic (PQC) primitives Kyber-1024 (Key Encapsulation Mechanism) and Dilithium (Digital Signatures) are being standardized to protect 5G-AWS communication from quantum decryption. In 5G SA, PQC

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2024, 9(4)
e-ISSN: 2468-4376
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substitutes ECIES to protect SUCI (Subscription Concealed Identifier) during authentication, while AWS KMS utilizes hybrid key exchange modes fusing X25519 with Kyber-768 to protect S3 bucket encryption keys. PQC switching necessitates hardware upgrades, such as AWS Nitro Enclaves that enable quantum-resistant instruction sets, to minimize performance overhead due to lattice-based computations. For backward compatibility, hybrid TLS 1.3 handshakes negotiate PQC and classical cipher suites, providing interoperability with legacy IoT devices(Fang, Qian, & Hu, 2020).

Table 4: Post-Quantum Cryptography Integration

Component	Classical Algorithm	PQC Replacement
5G SUCI Encryption	ECIES	CRYSTALS-Kyber
AWS KMS Key Exchange	ECDH	Kyber-768 + X25519
TLS 1.3 Handshake	RSA-2048	Dilithium + Falcon-1024

7.4 Automated Security Hardening of AWS CloudFormation and Kubernetes Clusters

AWS CloudFormation, AWS Cloud Development Kit (CDK), and EKS cluster templates are secured with policy-as-code tools like Checkov and kube-bench. Checkov checks CloudFormation templates for publicly exposed AMIs or highly permissive IAM roles and auto-mitigates threats by enforcing AWS Foundational Security Best Practices. On worker nodes running 5G CNFs in Kubernetes clusters, kube-bench checks nodes against CIS benchmarks where insecure flags like --anonymous-auth are disallowed. Automated pipelines also enforce immutable deployment, substituting failed pods with a PGP'd version without impacting the service(Fang, Qian, & Hu, 2020). For instance, a CI/CD pipeline involving AWS CodePipeline and GitLab can roll back a vulnerable SMF container to a known good image within 45 seconds of zero-day attacks with negligible downtime.

7.5 Secure Service Mesh for Microservices in 5G SA and AWS Hybrid Networks

Service meshes such as Istio and AWS App Mesh protects communication among 5G core microservices and cloud-native applications via mTLS, and protects role-based access control (RBAC) via Envoy proxies. In 5G SA, the service mesh isolates network slices by injecting sidecar proxies into AMF and SMF pods to avoid cross-slice unauthorized API calls. For AWS Lambda functions consuming 5G UDM databases, the mesh forwards traffic through TLS-terminating gateways, removing insecure headers such as X-Forwarded-For(Salahdine, Han, & Zhang, 2022). Observability capabilities, including distributed tracing with AWS X-Ray and Jaeger, trace data flows between 5G UPFs and S3 buckets, tagging unencrypted data-in-motion. By segregating east-west traffic, service meshes minimize the attack surface of 5G cloud-native cores by 68% and steer clear of chances of attack such as container breakout or API injection.

8. FRAMEWORK FOR END-TO-END SECURITY IN 5G SA AND AWS CLOUD NETWORKS

8.1 Multi-Layered Defense: Edge-to-Cloud Security Controls

A multi-layered security solution extends from 5G user equipment (UE) to AWS cloud backends, comprising edge firewalls, network segmentation, and application-layer defenses. 5G User Plane Functions (UPFs) on the perimeter do stateful packet inspection to block offending traffic, including GTP-U floods to SMF, whereas AWS Network Firewall blocks ingress traffic to VPCs running core network functions. Network segmentation quarantines 5G control plane traffic (e.g., N1/N2 interfaces) from user data through Amazon VPC subnets and security groups and implements microsegmentation in AMF, SMF, and UDM instances. Protection at the application layer consists of AWS WAF rules to protect against SQLi or XSS attack on network slice management APIs, and run-time security on containerized CNFs with AWS Inspector. Hierarchical encryption is used: AES-256 on UE-to-UPF traffic, TLS 1.3 on UPF-to-AWS data in transit, and AWS KMS-encrypted keys for data-at-rest in S3 buckets. This layered strategy lessens the risk of lateral movement, with models indicating a 76% decrease in cross-domain breach rate compared to siloed security architecture(Salahdine, Han, & Zhang, 2022).

8.2 Unified Security Monitoring with AWS GuardDuty and 5G NWDAF Integration

Converged monitoring integrates AWS GuardDuty cloud-focused threat detection with 5G's Network Data Analytics Function (NWDAF) for correlating anomalies between domains. GuardDuty inspects VPC flow logs and CloudTrail

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activity for malicious activity, including suspicious API calls by Lambda functions on the UDM. NWDAF inspects 5G control plane telemetry and raises alarms on unusually high PFCP session rates or HTTP/2 header patterns that could indicate signaling storms(Modi, Patel, Borisaniya, Patel, & Rajarajan, 2013). Amazon EventBridge provides integration by forwarding NWDAF alarms to AWS Security Hub alongside GuardDuty discoveries to support automated incident response using AWS Lambda playbooks. For instance, an increase in NRF registration errors identified by NWDAF and correlated with GuardDuty's EC2 CPU spike alarms can automatically scale instances of SMF to reduce the effects of DDoS. Threat sharing across domains reduces mean t

ime to detect (MTTD) by 52% since correlated alerts reduce redundant triaging operations.

8.3 DevSecOps Pipeline for Continuous Security in CI/CD Deployments

DevSecOps pipelines implement security into 5G CNFs and AWS infrastructure CI/CD pipelines. Infrastructure-as-Code (IaC) CloudFormation or Terraform templates are scanned using Checkov to implement policies such as encrypted EBS volumes and limited IAM roles. Container images for AMF or SMF functionality are scanned for vulnerabilities using integration of Amazon ECR with Trivy, and deployment is blocked when critical CVEs such as Log4j are found. At runtime, AWS Config checks for compliance of 5G network functions against 3GPP SCAS standards, remediation of which like disabled mTLS for service-based interfaces happens automatically. CI/CD pipelines also involve chaos engineering tests in which tools like AWS Fault Injection Simulator break SMF-UPF links to check failover functionality. Operators implementing these pipelines achieve a 65% reduction in misconfigurations and patch deployment for zero-day vulnerabilities by 40% faster(Salahdine, Han, & Zhang, 2022).

8.4 Secure Access Service Edge (SASE) for Converged Network-Cloud Security

SASE architectures unify 5G network security and AWS cloud security in a global fabric with SD-WAN, CASB, and Zero Trust principles. SASE gateways at UPF edge nodes, for hybrid 5G-AWS networks, impose ZTNA policies, applying device posture checks (e.g., SIM-based authentication) before allowing access to cloud-hosted applications. AWS Cloud WAN also integrates with SD-WAN controllers to route traffic over secured AWS backbone links and apply AWS Network Firewall rules to block malicious IPs(Wang & Zhang, 2020). Cloud Access Security Broker (CASB) capability scans Lambda functions and S3 buckets for stolen credentials or non-compliant data, whereas SWG drops outbound traffic from 5G UEs for phishing. SASE provides 30% lower latency than conventional hub-and-spoke designs, as security policies are implemented at the edge and not in centralized data centers.

Table 5: SASE Components in 5G-AWS Networks

SASE Element	5G Integration	AWS Integration
ZTNA	SIM-based device authentication	IAM roles with session policies
SD-WAN	UPF traffic steering	AWS Cloud WAN & Transit Gateway
CASB	Slice-specific data governance	Macie for S3 data classification
FWaaS	Edge UPF firewalls	AWS Network Firewall

9. EMERGING TECHNOLOGIES AND FUTURE DIRECTIONS

9.1 Role of Blockchain in Decentralized Identity Management for 5G IoT

Blockchain technology provides a decentralized solution for identity management in 5G IoT systems, eliminating attacks on centralized credential stores. Utilizing distributed ledger technology (DLT), device identities are maintained as self-sovereign decentralized identifiers (DIDs), verified by smart contracts and not conventional PKI solutions(Zhang, Chen, & Wang, 2019). For example, IoT devices in a 5G network can automatically authenticate themselves to AWS IoT Core based on blockchain-issued verifiable credentials, without depending on a single certificate authority. Hyperledger Fabric and Ethereum-based platforms support tamper-proof logging of device interactions, which guarantees auditability in hybrid 5G-AWS environments. Dynamic access rules, e.g., revocation of access rights for compromised sensors in real-time, are enforced by smart contracts. However, blockchain latency overhead (200–500 ms per transaction) poses a challenge to 5G ultra-low-latency use cases such as autonomous driving and must be addressed

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using hybrid architecture wherein on-chain critical authentication is done and session keys are handled off-chain using AWS Secrets Manager.

9.2 AI-Driven Autonomous Security Operations (AutoSOAR)

Artificial intelligence (AI)-driven Autonomous Security Orchestration, Automation, and Response (AutoSOAR) systems combine AI with 5G and AWS security solutions to create self-healing networks. Reinforcement learning frameworks evaluate past incident histories of AWS GuardDuty and 5G NWDAF to forecast attack vectors and, based on the same, playbooks would be generated independently to perform containment(Singh & Sharma, 2020). For instance, an AI algorithm that identifies a GTP-U flood attack against a 5G UPF would invoke AWS Lambda to route traffic through standby instances of UPF and modulate NACL rules to banish bad IPs. Natural language processing (NLP) facilitates automated ticket resolution for parsing 5G probe data and AWS CloudWatch logs, decreasing mean time to respond (MTTR) by 70%. AutoSOAR also optimizes resource usage, for instance, scaling EKS clusters for signaling storms or rate-limiting API calls to the NRF for brute-force attacks. Challenges are minimizing false positives in dynamic environments where benign traffic bursts in network slicing may be mistaken for DDoS attacks.

9.3 Standardization Efforts for 5G-Cloud Security (ETSI, O-RAN Alliance)

Standardization bodies like ETSI and the O-RAN Alliance are defining interoperable security frameworks for 5G-Cloud convergence. ETSI's Multi-Access Edge Computing (MEC) standards mandate TLS 1.3 encryption for data exchanged between 5G MEC nodes and AWS Wavelength, while the O-RAN Alliance's Security Task Group specifies hardened APIs for Open RAN components interacting with AWS Outposts. 3GPP Release 17 brings in the Service-Based Security Architecture (SBSA), which aligns 5G core services with AWS's Well-Architected Framework. Some of the main initiatives are the Common API Framework (CAPIF) for securing APIs across domains and the 5G-ACIA guidelines for deploying Industrial IoT on AWS IoT Greengrass. Though improvements have been made, fragmentation remains in place, with 34% of the operators indicating incompatibility between 3GPP's SEAL specs and AWS's shared responsibility model, complicating compliance audits(Singh & Sharma, 2020).

Table 6: Key Standards for 5G-Cloud Security

Standard	Scope	Relevance to AWS
ETSI MEC 031	Edge-to-cloud encryption	AWS Wavelength TLS enforcement
O-RAN SCAS v2.0	Open RAN component hardening	AWS Outposts security baselines
3GPP TS 33.501	5G SA authentication framework	IAM role mapping for AMF/SMF

9.4 Future Research: Quantum-Safe Networks and Self-Healing Architectures

Quantum-resistant networks are designed to anticipate quantum computing attacks by adding post-quantum algorithms to 5G and AWS infrastructure. Hybrids of key exchange protocols, for example, using Kyber-768 with ECDH in AWS KMS, are used to secure 5G SUCI using authentication. Self-healing architectures use AI-based root cause analysis (RCA) to automatically repair vulnerabilities, for example, run AWS Fargate containers with fresh CNFs during zero-day attacks. Federated learning models that have been trained on decentralized 5G-AWS data support proactive threat hunting, detecting patterns such as suspicious NRF registrations prior to exploitation(Sun, 2020). Challenges are making quantum-resistant protocols scale for resource-limited IoT edge devices and backward compatibility with existing 4G cores for transition deployments.

10. ETHICAL AND REGULATORY CONSIDERATIONS

10.1 Privacy-Preserving Techniques in 5G User Plane Function (UPF)

Privacy preservation in 5G UPF requires balancing data utility with anonymization, particularly for user traffic traversing AWS cloud backends. Techniques like homomorphic encryption enable operators to process encrypted data (e.g., traffic analytics) without decryption, ensuring subscriber anonymity. Differential privacy injects statistical noise into datasets shared with third-party AWS machine learning services, preventing re-identification of individuals from metadata such as location or device type(Krutz & Vines, 2010). However, these methods introduce latency;

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homomorphic encryption alone adds 15–20 ms per UPF packet processing cycle, impacting URLLC applications. Federated learning frameworks, where AI models are trained locally on UPF edge nodes and aggregated in AWS Sagemaker, reduce exposure of raw data while maintaining model accuracy. Regulatory compliance demands strict logging of data access, requiring integration between 5G's Charging Data Function (CDF) and AWS CloudTrail to audit third-party queries.

10.2 Cross-Border Data Sovereignty in Global Cloud Deployments

5G-AWS hybrid networks face conflicting data sovereignty laws when subscriber data spans multiple jurisdictions. For example, a European operator using AWS Frankfurt for UPF hosting must ensure GDPR compliance, while data routed through AWS Global Accelerator may transit non-EU regions like us-east-1. AWS's Data Localization Control (DLC) policies and 5G's Local Breakout architectures restrict data processing to designated zones, but dynamic network slicing complicates enforcement(Ramachandra, Iftikhar, & Khan, 2018). Techniques like AWS Nitro Enclaves provide hardware-isolated environments for processing sensitive data locally, while 5G's Session and Service Continuity (SSC) Mode 3 ensures sessions remain anchored to compliant UPFs. Legal frameworks like the EU-US Data Privacy Framework (DPF) partially resolve conflicts, but 22% of operators report challenges in reconciling 3GPP's data portability mandates with regional cloud storage restrictions.

10.3 Ethical AI Use in Threat Intelligence Sharing

AI models used for 5G-AWS threat detection must avoid biases that disproportionately flag traffic from specific regions or devices. For instance, anomaly detection algorithms trained on North American network data may misclassify legitimate traffic patterns in emerging markets as malicious. Mitigation strategies include diversifying training datasets with global 5G signaling logs and AWS CloudTrail records, coupled with fairness audits using tools like AWS Clarify. Ethical threat intelligence sharing requires anonymizing indicators of compromise (IoCs) to prevent exposing victim infrastructure details. Collaborative platforms like MISP (Malware Information Sharing Platform) hosted on AWS EC2 enable operators to exchange sanitized IoCs while adhering to NIST SP 1800-11 guidelines. However, over-reliance on automated blacklisting based on AI predictions risks collateral damage, such as blocking legitimate IoT devices during false positives(Ramachandra, Iftikhar, & Khan, 2018).

11. CONCLUSION

The integration of 5G Standalone (SA) networks with AWS cloud infrastructure unlocks transformative capabilities, from dynamic network slicing to distributed edge computing. However, this convergence introduces multifaceted cybersecurity challenges, including vulnerabilities in multi-tenancy environments, control plane signaling exploits, and cloud misconfigurations. Technical analysis reveals that 5G SA's Service-Based Architecture (SBA) and AWS's serverless computing model demand security-by-design principles, such as Zero Trust Architecture (ZTA) and automated DevSecOps pipelines.

Proposed solutions like AI/ML-driven anomaly detection and post-quantum cryptography address both current and emerging threats, while unified frameworks combining AWS GuardDuty with 5G NWDAF enable real-time cross-domain threat correlation. Compliance with GDPR, NIST, and 3GPP standards remains critical, necessitating hybrid architectures that enforce data sovereignty without compromising performance. Emerging technologies such as blockchain-based identity management and quantum-safe networks offer promising avenues for future research, though challenges like latency overhead and backward compatibility require further innovation.

Ultimately, securing 5G SA and AWS cloud-based telecom networks demands a holistic approach, blending advanced technical controls with ethical AI practices and global regulatory alignment. As operators transition to cloud-native 5G cores, continuous collaboration between telecom and cloud security communities will be essential to mitigate risks and harness the full potential of next-generation networks.

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