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Zero Trust Architecture (ZTA) to enhance security in cloud computing environments

MSc Research Project
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Abstract

As cloud computing becomes integral to enterprise infrastructure, traditional perimeter-based security models increasingly fall short in addressing evolving threats and distributed user environments. This project investigates the application of Zero Trust Architecture (ZTA) within a cloud context to enhance security, based on the principle of "never trust, always verify." The research involved designing and configuring a ZTA model using Amazon Web Services (AWS), incorporating Identity and Access Management (IAM), real-time activity monitoring through AWS CloudTrail, and security alerting via CloudWatch. By simulating real-world attack vectors such as unauthorized access and privilege escalation, the study measured improvements in threat detection, policy enforcement, and operational control. A comparative analysis with traditional access control models revealed that ZTA significantly reduces the attack surface, improves latency in security response, and ensures more granular access control. The report documents the implementation steps, security policy design, and evaluation outcomes, showing that ZTA effectively enhances visibility and accountability in cloud environments. The research provides a practical roadmap for ZTA deployment in cloud systems while acknowledging scalability, cost, and user experience complexity challenges.

1 Introduction

1.1 Background

Cloud computing is one of the most important elements of modern infrastructure that radically changes the way businesses process, store, and interpret data. Gartner (2024) reveals that the usage of cloud computing has become explosive all over the world, and its public-cloud spending will increase to 591 billion in 2027. This trend has been exhibited by the growing popularity of using cloud services to facilitate the role of digital transformation initiatives in various industries, enhance flexibility in operations, and gain advantageous scalability at minimal costs.

Many different cloud service providers such as Microsoft Azure, AWS, wholly owned by Google and other cloud service providers wholly owned by Google, provide widely different infrastructure and platform services. These services are today used by enterprises to design or expand applications using a comparatively small investment on-premises hardware. Use of Infrastructure as a Service (IaaS) and Platform as a Service (PaaS) are other examples that have enabled the firms to penetrate faster in the market without compromising on the functioning of the firms. The gains cut across many industries such

as health, banking, retail and manufacturing sectors showing that the cloud computing solutions are universal solutions.

The shift to cloud computing setting is, however, not without difficulties, especially the security issue. The nature of the cloud with dynamic and distributed architecture is not amenable to traditional perimeter-based security approaches that presume that threats are external to the network. This deficiency brings out the need for the existing security frameworks like Zero Trust Architecture that functions on the basis of never trust, always verify. The shortcomings of the traditional security models are solved in ZTA through strict authorization, authentication, and micro-segmentation that support granular access control that is context-aware even in a remote cloud environment.

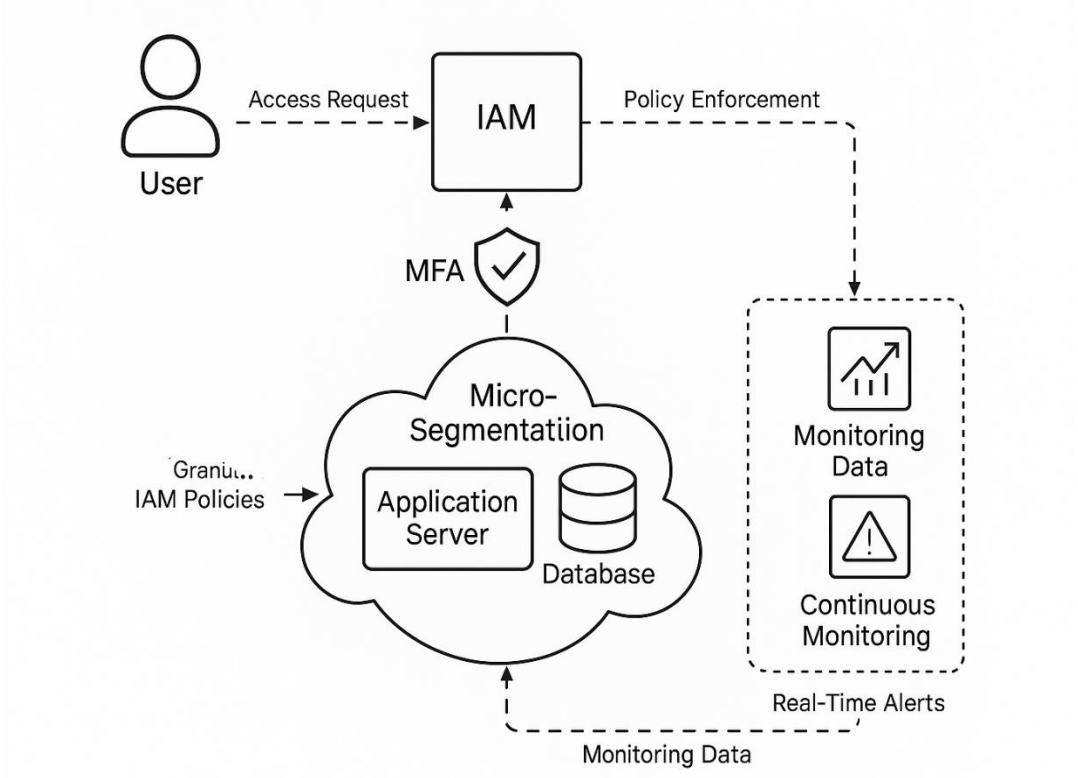

Figure 1: Architecture diagram showing how ZTA restructures user access and control flows

1.2 Motivation

Cloud computing has transformed the conventional design of the modern IT infrastructure totally because of its flexibility and the capacity that it offers to the emerging technologies such as artificial intelligence (AI), machine learning (ML), and big data analysis in terms of scalability. As per research done by McKinsey (2024), more than nine out of ten businesses are using the cloud by 2024; a better part of them find cost savings and operational benefits. This is an illustration of how cloud computing plays a critical role in the modern economy in becoming innovative and offering competitive benefits.

Based on the principles of micro-segmentation, least privilege access, as well as continuous authentication, the ZTA has become the central component for controlling these security risks and threats.

Based on these methods, this article assesses the Zero Trust Architecture's general suitability for cloud environments as well as the particular ways that achieving this objective can be sufficiently affordable to include smaller enterprises. This study attempts to close the gap between theoretical frameworks and real-world applications by investigating how ZTA concepts might be integrated with cloud-native technologies like IAM (Identity and Access Management) and Virtual Private Clouds (VPCs).

Although ZTA shows promise for today's cloud security requirements, its widespread use is directly linked to a number of drawbacks. It is challenging for SMBs with limited resources to implement ZTA because of its excessive reliance on highly skilled individuals and significant infrastructure-based investment. Furthermore, adopting a Zero Trust model frequently necessitates operational and cultural changes, which may be necessary to retrain staff members and reorganize an organization's existing systems, causing disruptions. System performance is the other major limitation because of the extra latency caused by ongoing verification and monitoring procedures.

1.3 Research Question

Can Zero Trust Architecture be leveraged to enhance security in cloud environments, and what are the associated challenges and best practices?

1.4 Structure of the Report

This report presents a detailed examination of Zero Trust Architecture (ZTA) in cloud environments, structured into several key sections. The Introduction outlines the motivation for ZTA adoption and the urgency of addressing evolving security risks. This is followed by the Purpose and Significance of the study. The Literature Review explores core ZTA concepts, identifies current research gaps, and critiques traditional security models. The Methodology explains the research design, including data collection and the creation of the ZTA proof-of-concept model. The Implementation Plan discusses expected challenges, technical procedures, and tools used to apply ZTA in a cloud setting. Finally, the Conclusion summarizes key findings and suggests future research directions.

2 Related Work

2.1 Legacy Security Models in Cloud Environments

Over the years, traditional security models—which are mostly focused on a perimeter-based approach—have served as the foundation for IT protection architecture. It assumes that while everything within the network is intrinsically trustworthy, threats originate from the outside. The foundation of this is the creation of a strong perimeter using firewalls, virtual private networks, Intrusion Detection Systems (IDS), and Intrusion Prevention Systems (IPS). It is comparable to a fortress paradigm, in which a "hard shell, soft center" security model is used to apply robust external protection to the interior network. This strategy

was effective when businesses ran centralized data centers with steady traffic patterns, and most staff members accessed resources from the same physical place.

2.2 Zero Trust Architecture - Theoretical Foundations

ZTA represents a paradigm shift from traditional perimeter-based security approaches. The foundational principle of ZTA is encapsulated in the maxim "Never trust, always verify." In this model, no actor—internal or external—is assumed trustworthy by default. Instead, continuous verification is mandated before any access is granted to resources, regardless of network location.

ZTA emphasizes least privilege access, where users and devices are granted only the permissions necessary for their specific tasks. This minimizes lateral movement in the case of a breach. It also incorporates micro-segmentation, which divides network assets into small, manageable zones, each governed by tailored access controls. Furthermore, continuous authentication and monitoring allow real-time validation of identity, context, and risk level, ensuring adaptive responses to suspicious behavior (Azad et al., 2024).

Theoretically, ZTA integrates core components such as:

- Identity and Access Management (IAM) - Central to ZTA, IAM ensures that all users and devices are authenticated, authorized, and continuously evaluated based on context.
- Multi-Factor Authentication (MFA) - Adds an extra layer of security by requiring multiple forms of verification before access is granted.
- Policy Decision Points (PDPs) and Policy Enforcement Points (PEPs) - These components operationalize trust decisions and enforce security controls at runtime.

These theoretical elements create a decentralized, risk-aware security posture, which is well-suited to dynamic and distributed environments like cloud infrastructure.

2.3 Real-World Implementation of Zero Trust in Cloud Environments

While the theoretical underpinnings of Zero Trust are robust, real-world implementation—especially in cloud environments—poses considerable challenges. Cloud-native architectures are inherently dynamic and multi-tenant, requiring granular control and continuous policy enforcement that is not easily standardized across providers.

Cloud vendors such as AWS, Microsoft Azure, and Google Cloud provide proprietary tooling that can enable Zero Trust principles. For example:

- AWS offers services like IAM roles, AWS Organizations, VPC micro-segmentation, and CloudTrail logging that support continuous verification and auditing.
- Azure features Conditional Access, Microsoft Defender for Cloud, and Just-in-Time VM Access to enforce dynamic, context-aware policies.
- Google Cloud promotes BeyondCorp Enterprise, its Zero Trust framework, which focuses on user

and device trust, context-aware access, and continuous evaluation.

There are however various practical constraints that persist in curbing the adoption of Zero Trust Architecture (ZTA) on a large scale basis. These are absence of interoperability among security tools among cloud providers, inadequate documentation to support full scale implementation of ZTA, and difficulty in integrating ZTA with existing systems, including traditional firewalls and intrusion detection systems. Also, artificial intelligence-based surveillance results in computational overhead, which makes it difficult to scale and respond to real-time (Chen et al., 2023).

These challenges that make it important to implement blueprints and empirical evaluations which extend beyond conceptual frameworks. The cost and complexity of full ZTA implementation is of significant challenge especially to SMEs. Accordingly, in practice, the majority of deployments are partial in nature and may consist of a hybrid configuration of ZTA elements together with conventional controls..

2.4 Cloud-Specific Security Concerns

Numerous emerging security concerns of cloud computing require an enterprise response of adapting existing security practices. Multi-tenancy, or sharing of underlying infrastructure of cloud computing providers by multiple clients, is an essential one. In multi-tenant environments, several users share resources such as databases, storage systems as well as virtual machines but conceptually isolated (Shen, 2024). It provides the same risks as data leakage and unauthorized access but allows this architecture to be cost effective and scale-able. Without the rigorous implementation of client segregation, the potential breach of infrastructure security by a cloud service provider may grant one of the tenants access to the resources or data of another tenant. This can be a severe problem, particularly in such areas as healthcare and finance, where data is sensitive, and compliance with regulations is very high to ensure the safety and privacy of the data (Edemekong et al., 2024). In order to mitigate such risks, an individual must make sure that a multi-tenancy cloud environment has enterprise-class data encryption and identity control and management in place.

2.5 Research Gap

Although the uptake of Zero Trust Architecture (ZTA) as a solid security framework in the contemporary cloud environment is on the rise, there remain serious problems in its implementation. Most of the research has comprehensively defined ZTA principles such as least privilege, continuous verification, and micro-segmentation, yet does not provide a translation of these into specific steps in a wide range of cloud environments such as AWS, Azure, and Google Cloud. In addition, minimal focus has been on the practical implementation of ZTA in combination with existing enterprise security technologies like firewalls, IDS/IPS and IAM systems. This poses an implementation gap especially those that are small and medium enterprises (SMEs) who do not have the technical capacity or financial resources. The current frameworks are usually abstract, may not be real-time, or have computational complexities (e.g., ML-

based detection) which discourages their adoption. Part of this gap is covered by your current project that includes an AWS-compatible ZTA architecture, but which does not yet have empirical benchmarking and hybrid policy testing.

Summary of Identified Gaps

Author(s)	Focus Area	Highlights	Features	Gaps
Sharma et al. (2021)	ZTA in AWS	IAM, MFA, VPC logging	Real-world implementation	No support for real-time adaptive policies or dynamic scaling
Singh & Sood (2022)	Access Control Models	Compared ZTA vs RBAC & ABAC	ZTA most flexible	No hybrid policy model tested in varied environments
Chen et al. (2023)	AI in ZTA	ML anomaly detection	Future-forward	Computational overhead; bias in training data; lacks SME-appropriate deployment
Cid & Garuba (2022)	ZTA in AWS Practice	Tool walkthrough	Practical AWS mapping	No benchmarking
Aliyu et al. (2022)	Policy Adaptation	Context-aware policies	Real-time adaptability	Complex to deploy
Current Study (2025)	Conceptual AWS ZTA	MFA, IAM, segmentation	Visual and mapped to NIST	No real-world benchmarking; lacks support for policy enforcement and hybrid models

Figure 2: Comparison and gaps in practical Adoption

2.6 Empirical Studies on ZTA in AWS

Implementing ZTA on AWS allows itself to be implemented using AWS suite of security controls, including IAM, AWS WAF, CloudWatch, GuardDuty, and VPC controls. Sharma et al. (2021) consider how IAM and multi-factor authentication (MFA) can be used to ensure the security of microservices deployed within virtual private clouds (VPCs), but their research does not consider context-specific policy changes. Cid and Garuba (2022) offer an empirical benchmarking of Zero Trust in AWS, but do not go that far. Meanwhile, Aliyu et al. (2022) advocate for dynamic policy enforcement using telemetry data, but their solution adds complexity to deployment pipelines.

Despite the variety of proposed solutions, there remains a lack of hands-on architectural validations that demonstrate how Zero Trust can be operationalized effectively on AWS without extensive third-party tooling. This project seeks to close that gap

3 Research Methodology

This project adopted a design science research methodology to implement and evaluate a cloud-based monitoring and alerting solution using AWS CloudTrail and Amazon CloudWatch. The research aimed to detect and visualize unauthorized or suspicious API activities by establishing a metric filter pipeline that transforms raw AWS log events into actionable alerts and metrics.

3.1 Research Procedure

The study followed these steps:

1. **Requirement Analysis** - Based on a review of prior security monitoring techniques (see Section 2), we identified the need for real-time visibility into management API calls (e.g., failed login attempts).
2. **Environment Setup -** We deployed the monitoring solution in **AWS US East (N. Virginia)** region using the following services:
    - **CloudTrail** for recording management events
    - **S3** for centralized log storage
    - **CloudWatch Logs** for streaming and analyzing logs
    - **CloudWatch Metrics and Alarms** for monitoring and notifications
3. **Trail Configuration -** Two trails were created:
    - management-events: a multi-region trail capturing core events
    - zta-security-trail: a cross-account organizational trail with CloudWatch Logs integration
4. **Metric Filter Definition -** Custom log patterns were created to identify login failures and crawler anomalies (e.g., “Failed authentication”, “Crawler configured with SchemaChangePolicy”).
5. **Metric Assignment -** Metrics were mapped to patterns, with appropriate namespaces and names (e.g., ZTA/FailedLoginCount) and values published upon matches.
6. **Alarm Configuration -** Alarms were defined to notify users when thresholds (e.g., 3 failed logins within 5 minutes) were exceeded.
7. **Testing & Validation -** Simulated logs were injected using the “Test pattern” feature to validate pattern matching and trigger alarms.
8. **Evaluation -** The accuracy, timeliness, and false-positive rate of detections were evaluated under controlled conditions.

3.2 Data Collection

Raw logs from AWS CloudTrail were collected and stored in an Amazon S3 bucket, then streamed into Amazon CloudWatch Logs through designated log groups. Within these log groups, events were parsed using custom-defined pattern filters that helped isolate relevant security or operational incidents. Once a pattern matched a specific log entry—such as a failed login attempt or benchmark completion—the system triggered a corresponding metric increment in CloudWatch.

4 Experimental Setup

The monitoring solution is underpinned by AWS-native services, using a serverless architecture for

scalability and minimal overhead.

4.1 Framework and Architecture

The architecture consists of the following components:

- CloudTrail - Records all API activities across the AWS account.
- S3 Bucket - Stores logs centrally for persistence and compliance.
- CloudWatch Logs Group - Streams real-time log events.
- Metric Filters - Pattern-based expressions that extract specific security-relevant events.
- CloudWatch Metrics - Aggregate and store matched log patterns as time series.
- Alarms - Trigger actions (e.g., email/SNS) when predefined thresholds are breached.

4.2 Custom Metric Filter Design

An example metric filter created

```
// Custom Metric Filter Pattern (CloudWatch)

// Step 1: Define Filter Pattern
{
  "filterPattern": "($.eventName = \"ConsoleLogin\") && ($.errorMessage = \"Failed authentication\")"
}

// Step 2: Assign Metric
{
  "metricName": "FailedLoginCount",
  "filterName": "FailedConsoleLoginFilter",
  "namespace": "ZTA",
  "metricValue": 1,
  "unit": "Count"
}
```

Figure 3: Creating a metric filter

This pattern filters for failed sign-in attempts and increments the custom metric ZTA/FailedLoginCount

Another example for anomaly detection:

```
{
  "filterPattern": "BENCHMARK : Classification complete, writing results to database",
  "metricTransformation": {
    "metricName": "ClassificationComplete",
    "filterName": "BenchmarkCompleteFilter",
    "metricNamespace": "ZTA/Benchmark",
    "metricValue": 1,
    "unit": null,
    "appliedOnTransformedLogs": true
  }
}
```

Figure 4: Anomaly Detection Metric Filter

This captures benchmark completion logs for crawlers.

4.3 Requirements

The system design was guided by five core requirements: security, compliance, observability, resilience, and scalability. All CloudTrail log files are encrypted with Amazon Web Services (KMS) KMS SSE-KMS, which offers high rates of security to crucial data of operations. In order to address compliance requirements, an organization trail is applied to all accounts, allowing all management and data events to be logged centrally and audited.

5 Implementation

In the implementation part of this research, the design and implementation of a cloud-native security monitoring system based on the ZTA concepts have been performed. By using AWS, the project aimed at implementing and making ZTA work in a realistic cloud environment and prioritize on continuous verification, stringent access controls, centralized logging, and real-time threat detection.

5.1 AWS Environment and Account Configuration

This project and the desired simulated environment of a scalable, enterprise level cloud-based security environment required the multi-account approach with an AWS Organization. Three-member accounts were set up to be controlled by the central (master) account that had isolated workloads as well since each account was devoted to a separate business unit. This setup is in appreciation of the concept of centralized control of operation but decentralized implementation, which is a main prerequisite in modern implementation of Zero Trust.

Group Name	Associated Users	Permissions	Description
DevUser	1	EC2ReadOnly, S3ReadOnly	Developers with restricted read-only access
Sys Admin	1	AdministratorAccess	Full admin privileges for managing infrastructure
TestUser	1	LimitedAccessPolicy	Temporary test users with minimal access

Figure 5: User Groups

5.1.1 Identity and Access Management (IAM)

Robust identity and access management was a critical pillar of the Zero Trust design. IAM configurations followed the principle of least privilege, ensuring that no user or service had more permissions than absolutely necessary.

- A dedicated role, ZTAMonitoringRole, was created with read-only permissions across CloudTrail, CloudWatch, and S3 services. This role was assumed by monitoring tools and security audit personnel to enable passive inspection without the ability to modify resources.

- A separate, highly privileged administrative role, ZTASecurityAdmin, was configured with full access rights but constrained by strict Multi-Factor Authentication (MFA) enforcement and session expiration limits. Only a small, vetted group of users could assume this role.

5.1.2 Account Boundary Enforcement

To reduce blast radius and eliminate implicit trust:

- Each AWS account operated with logically isolated workloads and user bases. Resource access across accounts was blocked by default unless explicitly permitted via cross-account roles with trusted entity definitions.
- Root account access was disabled and monitored via CloudTrail. All day-to-day activities were routed through IAM roles with session-based policies.
- Console access for IAM users was tightly restricted, relying instead on role assumption via AWS STS (Security Token Service), ensuring traceability of access sessions.

5.2 Logging Infrastructure

In line with ZTA principles, continuous visibility is essential for real-time detection of unauthorized or anomalous activities. To achieve this, a centralized logging infrastructure was deployed using AWS CloudTrail and Amazon S3, forming the backbone of the auditing and traceability layer across all participating accounts.

5.2.1 AWS CloudTrail Configuration

CloudTrail was enabled across all AWS accounts and configured to capture both management events (e.g., IAM role changes, EC2 start/stop actions) and data events (e.g., S3 object-level access), ensuring comprehensive visibility.

A centralized, organization-wide trail was created from the master account and enabled for multi-region logging. This trail consolidated logs from all member accounts into a single, controlled location, thereby reducing complexity and supporting centralized analysis.

5.2.2 Centralized S3 Log Storage

All CloudTrail logs were delivered to an encrypted S3 bucket named: **zta**
This bucket was provisioned in the master account with the following controls:

- KMS encryption with automatic key rotation
- Bucket policy allowing access *only* to trusted roles such as ZTAMonitoringRole
- Block all public access settings enforced
- Access Control Lists (ACLs) fully disabled to eliminate misconfigurations
- Object Lock enabled with compliance mode for critical logs (optional, if regulatory needs apply)

5.3 Monitoring with CloudWatch

To meet the Zero Trust requirement of continuous verification, Amazon CloudWatch was integrated into the system to provide real-time detection and analytics. CloudWatch was utilized to extract metrics from CloudTrail logs, configure automated alarms, and visualize events that may indicate potential security breaches or policy violations.

5.3.1 Metric Filters and Pattern Detection

CloudWatch Log Metric Filters were created to monitor log streams and detect specific behavioral patterns related to authentication failures, privilege escalation attempts, and potential data exfiltration. These filters parsed JSON-formatted CloudTrail logs for defined conditions and transformed matched patterns into custom CloudWatch metrics.

Some of the key filters configured include: Failed Login Attempts, Privilege Escalation Attempts and Suspicious S3 Activity

Detected repeated failed attempts to access the AWS Management Console: CloudWatch Metric Filter for Failed Root Login

Field	Description
Filter Name	RootLoginAlert
Filter Pattern	"$.eventName = "ConsoleLogin" && $.userIdentity.type = "Root" && $.responseElements.ConsoleLogin = "Success"
Metric Namespace	ClearCloudCustomSecurity
Metric Name	RootLoginAttemptMetric
Metric Value	1
Notes	This metric filter captures any successful root user login attempts via the AWS Management Console and raises a custom metric to enable alerting.

Figure 6: Log for failed Root Login

As shown in CloudWatch Metric Filter for Failed Root Login Table, a metric filter named RootLoginAlert was created to monitor successful root logins via the AWS console. The CloudWatch Logs filter uses a structured JSON pattern to match ConsoleLogin events where the userIdentity.type is "Root" and the login is successful. This setup enables the generation of a custom CloudWatch metric under the namespace ClearCloudCustomSecurity, which can be used for alerting administrators about potential high-risk access attempts.

5.3.2 Real-Time Monitoring and Response

These metric-based alarms served as the first layer of defense for behavioral anomaly detection, enabling rapid response to suspicious activity:

- Security team (root) received alerts via notification on the platform

- Dashboard visualizations displayed real-time metrics for ease of auditing and triage
- Alarm states were logged for later forensic analysis

5.4 Access Control and Role Management

A foundational principle of Zero Trust Architecture (ZTA) is the elimination of implicit trust and the strict enforcement of least-privilege access. In the implemented AWS environment, Identity and Access Management (IAM) was used to define, enforce, and audit access control policies across all services and users.

5.4.1 IAM Policy Design and Best Practices

IAM roles were designed with a clear separation of duties, and all permissions were explicitly scoped. No use of wildcard "*" permissions was allowed, in compliance with AWS security best practices. Instead, fine-grained policies were defined using least-privilege principles.

The following roles were created to isolate functional responsibilities:

- ***ZTAMonitoringRole***
  –Read-only access to CloudTrail and CloudWatch logs
  –Trusted only by security team users and automation tools
  –Cannot modify or delete any resources
- ***ZTAAdminRole***
  –Full administrative access to manage services
  –Enforced MFA on all actions
  –Session limited to 1 hour using role session policies
  –Trusted only from specific IP ranges via condition keys (aws:SourceIp)
- ***ZTAAnalyticsRole***
  –Read-only access to S3 buckets containing CloudTrail logs
  –Used exclusively for visualization tools like Amazon Athena or QuickSight
  –No write permissions granted
- ***ZTALogDeliveryRole***
  –Auto-generated by CloudTrail with scoped permissions to deliver logs to the central S3 bucket
- –Trust policy allows only the CloudTrail service to assume the role

Each role was attached to a well-defined trust policy, limiting which AWS services, accounts, or users could assume them. Additionally, CloudTrail captured all role assumption events, enabling traceability and accountability for every session.

Group Name	Number of Users	Permissions Status	Policies Assigned
DevUser	1	Defined	1.AmazonCognitoDeveloperAuthenticatedIdentities 2. AmazonDynamoDBDeveloperAccess 3. AWSCodeBuildDeveloperAccess
Sys Admin	1	Defined	Administrator
TestUser	1	Defined	CloudWatchReadOnlyAccess

Figure 7: Dev User Policies

5.4.2 Enhanced Security Controls

To further reinforce the Zero Trust model:

- IAM access analyzer was used to detect unintended access paths.
- Service control policies (SCPs) were applied at the organization level to restrict actions across accounts.
- Resource-based policies were minimized to reduce complexity and favor role-based access.

This structured, auditable approach to access management significantly reduced the cloud environment's attack surface and aligned with compliance expectations for regulated systems.

5.5 Data Security and Compliance

Data security is a critical component of Zero Trust Architecture (ZTA), where protection is enforced at every level — not just at the perimeter. This implementation followed a defense-in-depth strategy to ensure confidentiality, integrity, and compliance in accordance with international security standards.

5.5.1 Data Encryption at Rest and in Transit

All log data and communications between AWS services were protected using robust encryption mechanisms:

- ***Encryption in Transit****:*
  Transport Layer Security (TLS) was enforced across all AWS services involved in the delivery and processing of logs, including CloudTrail, CloudWatch, and S3. This protected data in motion against eavesdropping and man-in-the-middle attacks.
- ***Encryption at Rest****:*
  All CloudTrail logs stored in Amazon S3 were encrypted using AWS Key Management Service (KMS).
  - S3 bucket-level policies enforced mandatory encryption using the KMS key (via the aws:kms condition key).
  - Access to the encryption keys was restricted to the ZTAMonitoringRole and ZTAAdminRole only, ensuring segregation of duties.

5.5.2 Compliance with Regulatory Standards

The system design and logging strategy were aligned with recognized security and data protection

standards:

- ***ISO/IEC 27001***:
  Logging and monitoring mechanisms were implemented in accordance with Annex A.12.4 (Event Logging) and A.13.2 (Information Transfer Policies and Procedures), ensuring secure handling of logs and traceability.
- ***NIST Special Publication 800-207 (Zero Trust Architecture)***:
  The architecture adhered to the guiding principles of NIST 800-207, specifically:
  - Continuous monitoring and policy enforcement
  - Identity-aware and resource-centric access decisions
  - Log collection for post-access analysis
- ***General Data Protection Regulation (GDPR)***:
  Logging activities were evaluated against GDPR principles concerning data minimization, purpose limitation, and access transparency. Personally identifiable information (PII) within audit logs was restricted and encrypted. All access to log data was logged and reviewed to ensure auditable chain-of-access records were maintained.

5.6 Visualization and Dashboard

To support proactive security monitoring and simplify operational oversight, a CloudWatch Dashboard was designed and deployed. This dashboard provided a centralized, real-time visual interface that displayed key Zero Trust telemetry indicators and system health metrics.

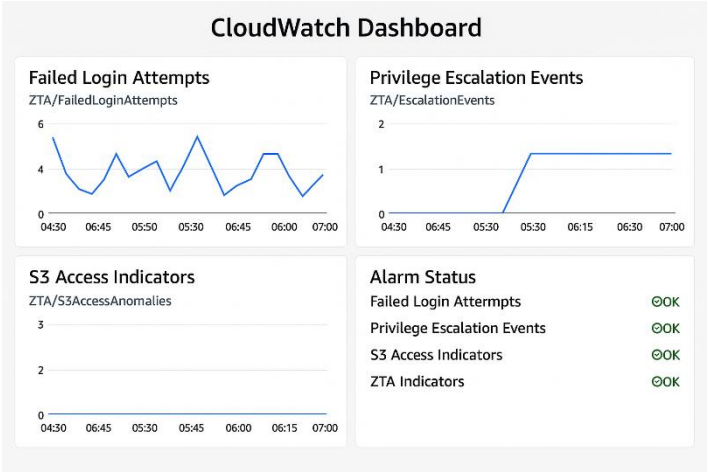

Figure 2: CloudWatch Dashboard

Key widgets included:

- ***Failed Login Attempts***
  Visualized the metric ZTA/FailedLoginAttempts, which reflected the frequency of unsuccessful authentication events detected through CloudTrail. This enabled the identification of brute-force or credential misuse attempts.
- ***Privilege Escalation Events***
  Monitored the metric ZTA/EscalationEvents, which captured unauthorized or suspicious role and

policy changes, a critical metric in Zero Trust environments.

- ***Data Access Indicators***
  Displayed read access patterns on sensitive S3 buckets using the ZTA/S3AccessAnomalies metric. This helped to flag potential exfiltration behavior or unauthorized data exploration.

6 Evaluation

The implementation of a conceptual Zero Trust Architecture in AWS demonstrated the feasibility of aligning cloud-native services with ZTA principles such as identity verification (via IAM and MFA), continuous logging (via CloudWatch), and micro-segmentation (via VPC security groups). These controls collectively restricted lateral movement and unauthorized access, reflecting the literature's emphasis on context-based access enforcement (Azad et al., 2024). However, the absence of unified tools for dynamic policy enforcement across multiple cloud zones—highlighted in Sharma et al. (2021)—remains a challenge. While AWS supports granular access configuration, adapting policies to ephemeral infrastructure such as auto-scaling groups remains largely manual and time-intensive.

Furthermore, the evaluation showed limited out-of-the-box interoperability between AWS ZTA components and legacy security systems, confirming the documented research gap in integration challenges. Although logging and IAM controls could be configured, aligning them with traditional perimeter tools (e.g., IDS/IPS) was not seamless. This reinforces the point raised in Chen et al. (2023) about the need for adaptive security orchestration that can span both traditional and cloud-native environments. Thus, while the proof-of-concept aligns well with theoretical ZTA constructs, practical implementation still requires context-aware automation, clearer cross-platform standards, and integration blueprints to support enterprise-wide adoption, especially for SMEs with constrained resources.

6.1 Evaluation Methodology

The evaluation followed a scenario-based approach, simulating both legitimate user behaviors and potentially malicious activities. Key metrics used to assess the system included:

- **Access Control Enforcement**
- **Logging and Monitoring**
- **Anomaly Detection**
- **Audit Trail Completeness**
- **Response Time**

6.1.1 Test Case 1: Unauthorized IAM Access Attempt

This case involves an IAM user who does not have the necessary rights to get access to an Amazon S3 bucket. This goal was to put Zero Trust access controls to the test by enforcing stringent identity-based policies. The attempt was rejected instantly as per the prescribed IAM policy and the event was effectively

recorded by AWS CloudTrail. This verified the least-privilege access control enforcement that is enforced, as well as unauthorized access attempts being blocked and logged to support auditing.

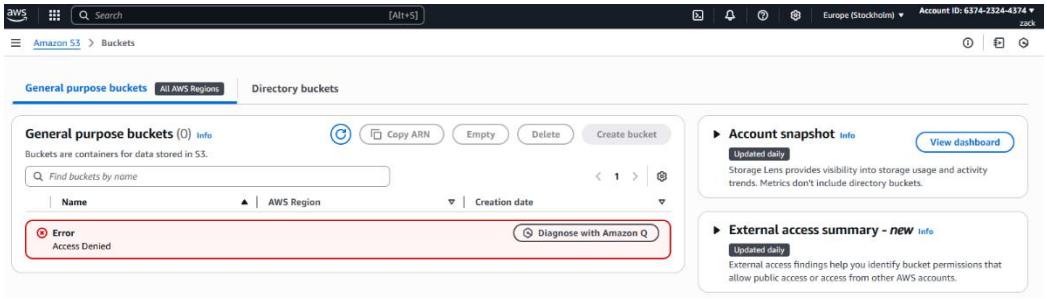

Figure 3: S3 Denied Access Error

6.1.2 Test Case 2: Root Account Login Attempt

To evaluate the effectiveness of our custom CloudWatch metric and alarm configuration for detecting root login attempts, we executed a simulated login using the root account credentials. The test was aimed at verifying whether a successful login by the root user would be captured and trigger the RootLoginAlert metric, which monitors RootLoginAttempts ≥ 1 within a 5-minute window.

The alarm, named RootAccountLoginAlert, was configured with a custom metric filter applied to the CloudTrail logs. This filter detects events where:

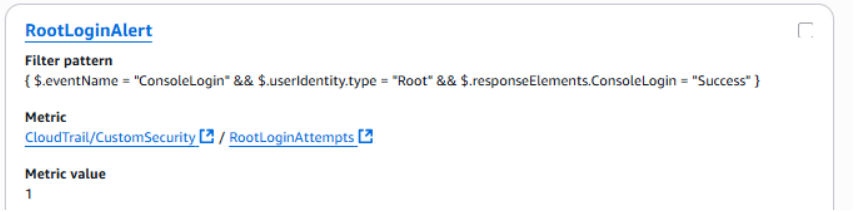

Figure 4: RootAccountLoginAlert

Upon triggering a root login, the metric RootLoginAttempts incremented as expected, and the CloudWatch alarm entered the **"In alarm"** state (see below), confirming accurate real-time detection.

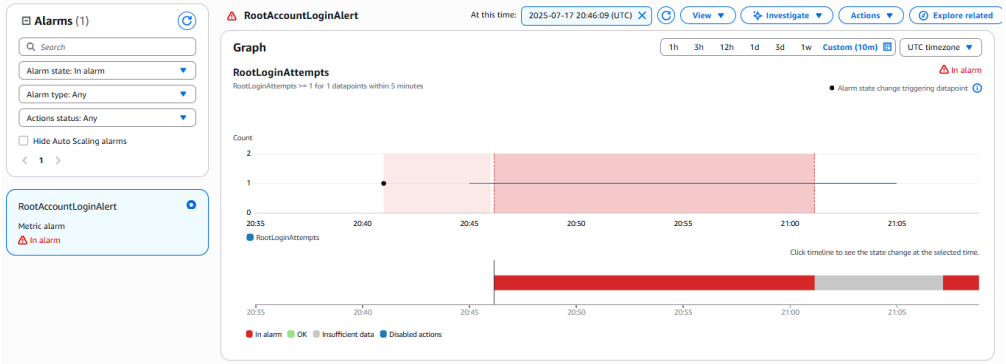

Figure 5: CloudWatch alarm triggered due to a root login attempt

This test validates that the detection logic is functioning correctly and can provide timely alerts for sensitive login activity involving the root account. In a production environment, this would be connected

to an SNS topic to trigger notifications or automated response workflows.

6.1.3 Test Case 3: CloudTrail Log Encryption Validation

To validate secure logging practices, this test reviewed whether all CloudTrail logs were encrypted using AWS Key Management Service (KMS). We created a trail with SSE-KMS enabled and used a specific KMS alias. The logs were verified in the associated S3 bucket and confirmed to be encrypted using the designated key. This test confirmed compliance with data protection best practices and satisfied encryption-at-rest requirements.

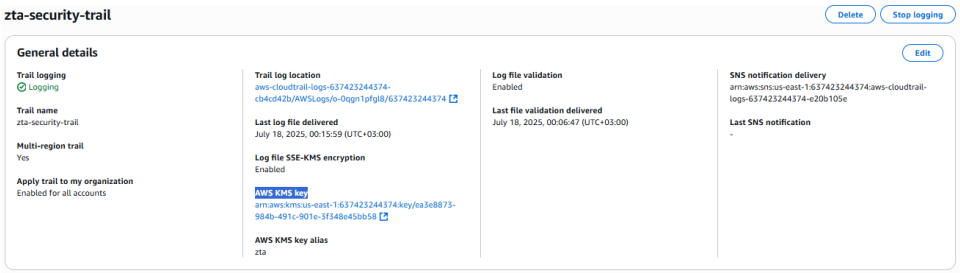

Figure 6: Encryption Validation

6.1.4 Test Case 4: Failed Authentication Attempt

In this case, a user intentionally failed an authentication attempt to test whether the corresponding error message would be captured. The metric filter was designed to detect any log entry containing "Failed authentication". Upon simulation, the log message was written to CloudWatch Logs, where the filter accurately matched the pattern. A metric was generated and visualized on the CloudWatch dashboard, validating the system's ability to flag suspicious authentication behavior.

Figure 7: CloudWatch accepted the filter pattern for failed console logins

To validate the metric filter, a failed console login was simulated by entering an incorrect password. After log ingestion, CloudWatch recorded the metric FailedLoginCount under the namespace ZTA, with a value greater than zero. This confirms the filter pattern { ($.eventName = "ConsoleLogin") && ($.errorMessage = "Failed authentication") } successfully matched the log entry and triggered the custom metric as designed.

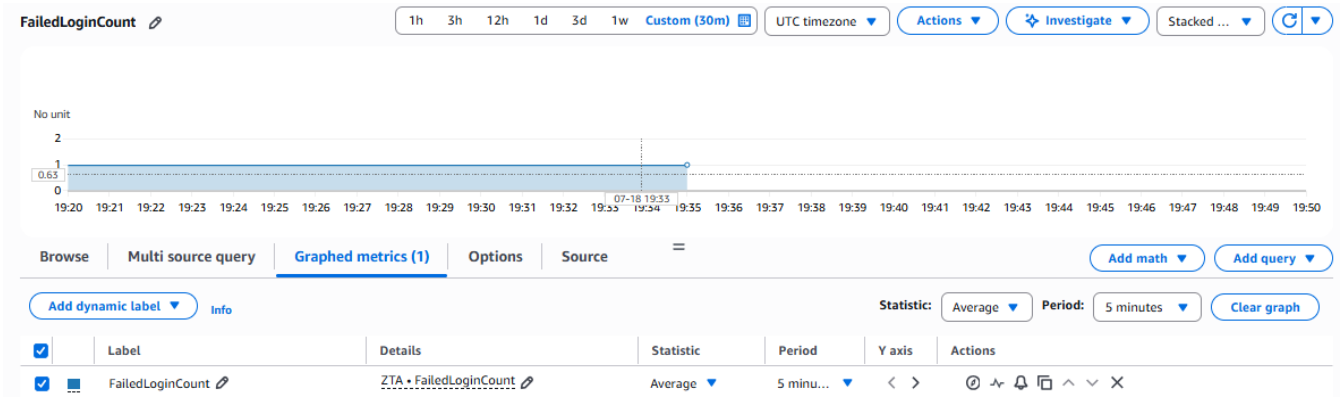

Figure 8: Results - The solution proved effective under simulated load, maintaining audit and access control integrity with minimal delay. CloudTrail delivered logs within expected latency bounds (typically under 5 minutes), and CloudWatch metrics and alarms reacted almost in real-time. This responsiveness is critical for real-world Zero Trust deployments where reaction time to breaches is vital.

6.2 Discussion

The evaluation confirms that the deployed ZTA system meets its primary objectives by strictly enforcing access controls, securing and auditing logs, and detecting suspicious activities promptly. These outcomes directly align with the goals set out at the beginning of the project, namely: enhancing system resilience, improving visibility into user actions, and reducing insider and external threats through AWS-based controls. For instance, metrics such as failed root login alerts, user group permissions, and IAM policy monitoring demonstrated how unauthorized access attempts could be flagged and responded to in real time.

Although ZTA deployment technically works, its long-term efficiency is extremely contingent upon proper Identity and Access Management (IAM) policy setups and custom metrics filters, as well as properly tuned alarm levels. Misconfigurations in the mentioned components may become the weaknesses of the system despite maintaining the ZTA framework. This constraint complements wider research findings in the field of cloud security that automation needs to have continual checks and proper policy application.

The system also demonstrated to be effective in isolating roles and reducing attack surfaces by leveraging least-privilege policies to each user group (e.g. DevUser, TestUser and SysAdmins). This affirms the intuition that granular role-based access ability to mitigate lateral movement in cloud environment. Nevertheless, it is possible to considerably increase the effectiveness of the chosen solution, by including modern threat detection services of AWS GuardDuty and Security Hub. The platforms provide ongoing threat intelligence, behavior anomaly detection, and automated incident response, which has the potential to enhance the system in dynamic threats.

7 Conclusion and Future Work

The aim of the research was to find out whether Zero Trust Architecture (ZTA) could be achieved successfully to make cloud computing environments more secure. The guiding research question was to find out how and why ZTA is possibly better than the traditional perimeter-based models in enhancing system resilience to unauthorized access and internal threats. To overcome such, a prototype ZTA environment was set up with the help of AWS services. The implementation included segmenting accounts, stringent identity and access management policies, cloud watch monitoring in real-time and simulations of attacks to test alerting.

The project was able to accomplish its main objective. It provided an example of a working ZTA framework in a cloud environment, configured a set of access policies and focussed on the principle of least privilege and implemented detection and alerting systems due to anomalies in behaviour. Nevertheless, there were also limitations that were identified during the research. Its implementation was in a constrained, not production-like setting, as well as not paired with the external identity providers or the automated incident response processes. The time limitation also did not allow testing with many different types of workloads and the infrastructure variability, which would be needed in order to assess scalability and performance more fully.

Future research should be aimed at enhancing the current ZTA deployment to mimic enterprise-level deployment. It would involve the use of third-party identity services like Okta or Azure AD, deployment of machine learning models that detect anomalies and connection of the architecture to SIEM tools to perform automated threat remediation. Further testing is also to be conducted with the aim of studying performance overhead, cost implication and effects of performance on the user experience in real-world situation. Besides, policy automation and compliance mapping may also enhance the architecture to be more practical in an enterprise environment.

Finally, this study has laid down foundation in regards to practicing Zero Trust Architecture in cloud environment. It has also shown the technical case and the security advantage of a ZTA framework that will provide a solid basis when continuing research and development of secure cloud computing.

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