Quantitative Feasibility Analysis of Zero-Trust Architecture Protocols: Comparative Evaluation in Resource-Constrained Autonomous IoT Systems

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1.Abstract

The massive increase in smart devices (Internet of Things and Operational Technology) has made traditional network defenses obsolete because they dangerously rely on implicit trust once a device is inside the network. This survey confirms that Zero-Trust Architecture (ZTA)—a "never trust, always verify" model—is the only viable approach for securing these distributed, low-power systems, as it fixes the failure of old security methods by enforcing continuous verification and micro-segmentation. We review current ZTA solutions, including AI-driven policy engines, decentralized blockchain validation, and the emerging Zero-Trust Foundation Models. However, our critical analysis reveals that ZTA is not yet fully practical due to two major hurdles: 1) The solutions are too computationally expensive and drain too much energy for small, resource-constrained IoT devices, and 2) The automated "trust scores" generated by AI are mathematically unreliable and unstable. Future research must therefore focus on designing resource-efficient ZTA architectures (using advanced techniques like Federated Learning and TEEs) and creating reliable, probabilistic models to accurately quantify device trust and uncertainty.

Keywords- Zero-Trust Architecture (ZTA), Autonomous IoT (A-IoT), FAST-SM9, AE-LSTM, Cybersecurity, Resource-Constrained Devices.

2. Introduction

2.1. Context: The Fragility of the Digital Infrastructure and the Magnitude of Autonomous IoT (A-IoT):

The modern digital environment as of the mid-2020s is defined by a basic security paradox: the large scale, unprecedented connectivity needed for modern industrial efficiency has created at the same time unprecedented levels of system fragility.[1] This connectivity is enabled by the exponential proliferation of Internet of Things (IoT) and Operational Technology (OT) devices. The number of active IoT devices has exploded and is expected to reach an estimated 18 billion worldwide in 2025, more than doubling at the end of the decade.[1] This explosive growth rate includes a heterogeneous set of devices, varying from deeply resource-constrained environmental sensors to complex and mission-critical autonomous industrial actuators.[1] The integration of these billions of devices into enterprise and critical infrastructure networks has effectively removed the very notion of network perimeter.[1] The transitional movement towards the Autonomous IoT (A-IoT) means that security failure modes are no longer confined to static, network based risks, but rather dynamic, self-propagating system threats.[2] As such, reliance on legacy security structures is proving disastrous and the need for intelligent, adaptive security and defence systems with the ability to operate autonomously is of paramount importance.[2]

2.2. Criticizing Legacy Models of Security and Zero Trust Imperative:

Legacy security paradigms, mostly Perimeter-Based Security Models (PBSM) and Identity-Driven Security Management (I-DMS) etc. are built on the fundamentally flawed notion of "implicit trust".[1] The fundamental assumption of this model is that once an entity has successfully authenticated at the network gateway, it is given broad, untethered lateral access to internal resources. In the complex and dynamic environment of autonomous IoT this implicit model

of trust is catastrophic; a single compromised edge device becomes an easily accessible beachhead adversaries will use in order to pivot laterally into critical control systems with minimal resistance.[1] Forensic analysis of recent breach after breach shows that the main failure mode of PBSM are its inability to contain this lateral movement.[1] In addition, the management of Access Control Lists (ACLs) for thousands of headless IoT devices is mathematically impossible to maintain manually, leading to the creation of static and easily exploitable permissions.[1] Zero-Trust Architecture (ZTA) offers the mandatory paradigm shift to counter this vulnerability. ZTA requires a strict "never trust, always verify" approach, in which the identity, health and request context of every entity must be continuously verified on a per-session basis, regardless of where it resides on the network.[1]

2.3.Problem Statement: Measuring ZTA Efficiency in Resource Limited Environments:

The widespread adoption of ZTA in resource-constrained IoT systems has historically been hindered by a very real operational challenge: the assumption that the continuous cryptographic verification required by ZTA has unacceptable penalties to device latency and energy consumption.[1] This perception creates a critical "security vs. efficiency" trade-off, which has been a significant barrier to the deployment of resilient A-IoT systems, especially those that rely on battery power and real-time processing.[4] The historical concern is that the continuous computational load required by the cryptographic operations would drain batteries too quickly and introduce unacceptable lag to real-time industrial and critical control processes.[1] The proven theoretical need of ZTA (as expressed by NIST SP 800-207[1]) dictates quantitative proof of its operational viability. Therefore, there arises a need for a stringent evaluation to prove that modern and lightweight ZTA protocols can break the limitations of traditional cryptography when implemented in resource-constrained edge environments.[1]

2.4.Research Objectives and Contributions:

This research offers a rigorous quantitative feasibility analysis from 2025 experimental data in order to conclusively answer the ZTA efficiency gap. The following are the specific objectives: To criticize inherent failure modes of legacy PBSM and I-DMS in heterogeneous autonomous IoT systems.[1] To quantitatively assess the computational and energy overhead of modern lightweight ZTA protocols - in particular the Unified Enhanced FAST-SM9 algorithm - relative to the traditional Public Key Infrastructure (PKI) using RSA-2048 and Elliptic Curve Cryptography (ECC) methods.[1] To examine the increased resilience of ZTA architectures, especially those using A.I. based policy engines and micro-segmentation, to sophisticated adversarial methods through penetration testing data.[1] To show the operation of continuous verification in resource-constrained edge devices. The main result of this research is the final quantitative evidence which confirms that modern implementations of ZTA offers reduced authentication latency (56.6% reduction) and energy consumption (63.0% reduction), thus refuting the long standing constraint that ZTA is too resource-intensive for edge computing.[1]

3. Related Work and Architectural Basis

3.1. Zero-Trust Imperative and Main Components of the Architecture:

The ZTA framework is based on core components defined by NIST SP 800-207[1], mainly including the Policy Engine (PE), the Policy Administrator (PA) and the Policy Enforcement Point (PEP).[1] The PE is responsible for determining the policy decision, the PA handles policy updates and the PEP enforces the access decision on the network boundary.[5] For highly distributed and autonomous IoT environments, these components must have sub-millisecond latency.[1] Recent academic research has highlighted the need to decentralize these core components to remove single points of failure, with blockchain technology often integrated to ensure verifiable, distributed identity management.[1] E.g. the Quantum-Resilient Blockchain-ZKP Privacy Authentication Framework (QBC-ZKPAF) presents an example of a blockchain-enabled ZTA capable of high throughput and minimum energy expenditure specifically designed for IoT environments.[1] The architectural need for high speed distributed trust calculation has led to the adoption of multi-layered architectures that leave enforcement to edge-level

3.2. Cryptography on the Lightweight and Identity Based Schemes:

The reason for the efficiency barrier in IoT security is that traditional cryptographic schemes carry quite a computing weight. Traditional PKI, which is often based on large keys like RSA-2048, has a significant performance overhead that affects especially the key generation and digital signing process.[9] This performance overhead is not acceptable for the frequent re-authentication required by ZTA.[9] While standard Elliptic Curve Cryptography (ECC), including TinyECC, provides better performance than RSA, it still maintains the complexity resulting from key management in certificate handling.[1] A great architectural innovation is the use of identity-based cryptography (IBE), a method of key management that reduces the burden of key management by obtaining cryptographic keys from user or device identities without the old-fashioned overhead of certificate infrastructure.[10] The Unified Enhanced FAST-SM9 algorithm, proposed in 2025, is a specific example of an identity-based cryptographic scheme designed to overcome the efficiency limitations for ZTA in IoT.[1] The fundamental efficiency mechanism of FAST-SM9 is that it innovatively combines the computationally separate processes of authentication and digital signature verification into a unified one-pass operational process.[11] This architectural optimization immediately translates into a 40% decrease in the number of communication rounds, which is immediately reflected in a reduction in latency and a drastic reduction in energy consumption, which makes continuous verification feasible for battery-powered sensors.[12]

3.3. Adaptive Policy Enforcement using AI:

Addressing the scale, complexity and sophisticated adversarial threats of A-IoT requires intelligent adaptive defense systems.[2] AI-Enhanced Zero Trust Frameworks (AIZTF) offer the capability for continuous, dynamic security policy enforcement needed by ZTA.[13] The Control Layer of such a framework usually makes use of hybrid deep learning types, such as Autoencoder - Long Short - Term Memory (AE-LSTM) Networks, for real-time, context-aware detection of anomalies.[1] AE-LSTM Networks employ the Autoencoder part to determine a baseline of "normal" behaviour of a device (fingerprints & communication patterns) while the LSTM part adds temporal awareness in detecting anomalous sequence or deviations.[13] Through empirical evaluation, these AIZTF models have been shown to be highly accurate in detection and have achieved 96.8% accuracy in real-time threat detection.[1] This integration forms the critical feedback loop that enables the Policy Engine (PE) to dynamically compute device trust scores and enforce adaptive, context-aware policy decisions in real-time.

4. Materials and Methods

This work takes a strict methodology of comparative analysis, where the performance and security efficiency of modern lightweight ZTA is compared to legacy security models in three quantitative aspects: latency, energy consumption and adversarial resilience.[1]

4.1. ZTA Architecture Architecture Framework for A-IoT:

The system model analyzed is a three-layered ZTA architecture, where the main purpose is to achieve resource-constrained autonomous IoT systems. This framework represents at a conceptual level the operational environment used for the performance evaluation so that the policy enforcement is distributed and optimized over the whole system.

Table IV.1: The Three-Layer ZTA Architectural Framework for A-IoT

Layer Name	*Key Function*	*Primary ZTA Components*	*Technology Implementation*
Device Layer	Secure Identity and Data Lightweight Origin Verification (Source Trust)	Policy Enforcement Point (PEP) at the Edge	Lightweight Cryptography (FAST-SM9), Microcontrollers (Raspberry Pi 4B, Pico W)
Control Layer	Real-time Trust Decision and Policy Generation (Policy Decision Point)	Policy Engine (PE), Policy Administrator (PA)	AI-Enhanced Anomaly Detection (AE-LSTM), Dynamic Re-Authentication (zero-trust-DRA)
Network Layer	Traffic Containment and Access Restriction (Least Privilege)	Policy Enforcement Points (PEPs)	Micro-segmentation enforced by Software-Defined Networking (SDN) Controllers

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The Device Layer consists of the IoT nodes (sensors, actuators) themselves, which make use of lightweight hardware. The cryptographic operations based on the FAST-SM9 protocol are performed in the local environment on these resource-constrained microcontrollers.[1] The Control Layer is deployed on edge servers or local gateways and contains the Policy Engine (PE), which computes real-time trust scores based on the AE-LSTM anomaly detection model.[1] The Network Layer enforces the least privilege access decisions made by the PE using the micro-segmentation technique, which ensures that even a compromised device cannot move laterally beyond the explicitly authorized segment.[1]

4.2. Comparative Experimental Set Up and Variables:

The comparison strategy is focused on measuring operational costs of authentication and access control mechanisms.[15] The experiment compares the proposed lightweight ZTA protocol called FAST-SM9 against Traditional PKI (RSA-2048) and lightweight alternatives such as TinyECC.[1] The performance data was generated by controlled laboratory experiments using representative resource-constrained hardware consisting of Raspberry Pi 4B and Pico W microcontrollers with the intention of simulating typical industrial and consumer IoT endpoints.[1] The experimental design has optimized the effects of the choice of algorithm in terms of network dependent variables such as routing overhead or congestion to ensure repeatable and accurate measurement of the computational and energy costs.[16] The main Independent Variable in the performance evaluation is the selection of the cryptographic algorithm specifically (FAST-SM9, RSA-2048, or TinyECC), while the Dependent Variables are defined by the key evaluation metrics described in Section 3.4.

4.3. Procedure: Unified Enhanced FAST-SM9 Authentication Method: The authentication mechanism that is used within the ZTA Device Layer is based on the Unified Enhanced FAST-SM9 protocol, which is a lightweight, identity-based protocol combined with a dynamic re-authentication scheme (zero-trust-DRA). This protocol is especially developed to minimize computational and communication overhead using an Improved Single Package (ISP) structure.[11]

4.3.1. Pre-Configuration and Key Establishment: Before it is put to work a Key Generation Center (KGC) initializes the system: System Setup: The KGC creates the system parameters (pp) such as the master public key (P_pub) and master private key (s). Device Key Extraction: For a given Device A (identified by Identity), the KGC uses the master private key (s) to compute and provision the terminal private key (D_A) to the device's secure enclave securely.[11] This process removes all of the complicated certificate issuance and verification steps at the heart of traditional PKI.

4.3.2. Initial Authentication Flow (IAP using ISP Structure): The Initial Authentication Phase (IAP) deals with the device proving its identity and integrity in one step and in a single efficient operation: Request Generation (Device A): Device A creates the challenge message (m) and calculates its digital signature from its private key (D_A). Simultaneously, it builds up a time-sensitive Dynamic Identity Token (DIT) by adding multi-factor attributes (e.g. OTP_Seed, Identity, current Timestamp) using a Hash based Message Authentication Code (DIT = HMAC(OTP_Seed | Identity | Timestamp)).[11] Transmission: The combined authentication and signature package, the ISP structure, comprising the signed challenge (m), Identity, and the time-bound DIT is sent from device A to the Edge Server/Policy Enforcement Point (PEP).[12] Unified Verification (PEP/Server B): The PEP receives the ISP. It first ensures that the freshness and integrity of DIT are valid. Critically, the PEP then uses the bilinear pairing property (e) inherent in the SM9 algorithm to perform the identity authentication and the digital signature verification simultaneously within a single, unified operational pass.[11] This cryptographic unification is the source of the 40% reduction in the number of communication rounds in the protocol.[12] Access Decision: If the verification is successful, the Policy Engine (PE), based on the principle of least privilege, computes the initial trust score and issues a session token,

and the principles of micro segmentation are set up through network layer policies.

4.3.3. Zero-Trust Dynamic Re-Authentication (zero trust DRA): The Continuous Authentication Phase (CAP) uses the zero-trust-DRA mechanism to monitor device trust continuously and dynamically re-authenticate the device based on context-aware trigger which will avoid risks like session hijacking and credential leakage.[11] Trigger Conditions: Re-authentication is triggered by the Control Layer (PE) on the basis of conditions that are generated from the AI Policy Engine (AE LSTM) [11]:

4.3.3.1.Behavioral Anomaly: The AE-LSTM model identifies a statistically significant change in access frequency, amount of data or request type versus the baseline behavior that has been determined.[13]

4.3.3.2.Contextual Change: A change in inferred context such as a change of originating network location (e.g. IP address inference) or environment parameters is a trigger for mandatory re assessment.[11]

4.3.3.3.Time Window Expiration: The expiration of the predefined maximum period of allowable time for the current session token.[12]

4.4. Strict Definition of Evaluation Metrics and Variables:

In order to guarantee the rigor of the comparative study, all the performance and security metrics and all their associated variables are clearly defined. The comparison methodology is entirely dependent on these quantifiable outputs.

Table IV.2: Definition and Measurement of Comparative Evaluation Metrics

Metric Symbol	*Definition*	*Unit*	*Identified Variables and Comparison Parameter*
T_{auth}	Authentication Delay	Milliseconds (ms)	Independent Variable: Cryptographic Algorithm. Measurement: Time elapsed from request initiation to session token receipt.
E_{auth}	Energy Consumption	Millijoules (mJ)	Independent Variable: CPU load during cryptographic operations. Measurement: Energy drained by the microcontroller during the cryptographic handshake process.
Communication Cost	Data Overhead	Bytes	Independent Variable: Protocol Structure (PKI certificate vs. ISP structure). Measurement: Total cryptographic data exchanged during the authentication sequence.
ASR	Attack Success Rate	Percentage (%)	Independent Variable: Security Model (PBSM vs. ZTA Trust-Weighted). Measurement: Percentage of simulated adversarial attempts that successfully compromise the target asset.
FPR	False Positive Rate	Percentage (%)	Independent Variable: Trust Score Threshold; AI Model (AE-LSTM) sensitivity. Measurement: Percentage of legitimate traffic incorrectly flagged as malicious, leading to session termination or denial.

The measurement process is the process of monitoring the cryptographic operation execution time and energy drawn from the power supply of the hardware platform. The Eauth variable records the computational intensity directly and Tauth measures the impact of the operational latency to the user or autonomous control system.[18]

5. Results and Discussion

The analysis of the experimental data for the year 2025 provides a definite quantitative proof that modern ZTA protocols have made the architect highly efficient and therefore definitively refutes the historical concerns about overheads.[1]

5.1. Computational Efficiency: Latency and Energy Costs Analysis

The main obstacle to adopting ZTA - the perceived overhead of constant verification of cryptographic operations - is clearly demonstrated to be addressed by advanced identity-based protocols such as FAST-

SM9. A comparison against traditional Public Key Infrastructure (RSA-2048) shows significant performance improvements on resource constrained microcontrollers.[1]

Table V.1: Comparative Performance of Authentication Protocols (2025)

Metric	*Lightweight ZTA (FAST-SM9)*	*Traditional PKI (RSA-2048)*	*Improvement (ZTA vs. PKI)*
Authentication Delay (T_{auth})	22.7 ms	52.3 ms	56.6% Reduction
Energy Consumption (E_{auth})	4.2 mJ	11.7 mJ	63.0% Reduction
Communication Cost	464 Bytes	704 Bytes	34.1% Reduction
Failure Recovery Time	<=2.0s	>=5.0s	> 60% Faster

The data validates that the FAST-SM9 implementation results in a 56.6% in authentication latency (Tauth) and a 63.0% in energy consumption (Eauth) reduction than the standard PKI. This efficiency gain is crucial because it brings the energy cost of continual verification (4.2 mJ) well within the operational budget of battery-operated sensors which typically operate on tight power budgets. The causal factor for this performance improvement can be attributed to the cryptographic unification offered by the ISP structure in FAST-SM9, which reduces the key management and verification processes to streamline the operations involved, thereby decreasing the number of computations and communications.[11] The 34.1% reduction in communication cost further minimizes network bandwidth usage, which is critical for high-density IoT deployments.

5.1. Network Throughput And Scalability Analysis:

Beyond edge device performance, scalability in high-density networks (e.g. smart city infrastructure) is of utmost importance. Research undertaken on advanced decentralized ZTA frameworks confirms the fact that the Control Layer can efficiently manage massive transaction volumes. The QBC-ZKPAF framework, for example, showed it could maintain a high throughput of 700 Transactions Per Second (TPS) with a low energy consumption of only 0.7 Joules per transaction. This throughput guarantees that decisions made by ZTA policies do not become a bottleneck in environments characterized by rapid and multiple parallel data exchange. Furthermore, ZTF frameworks specifically devised for 6G network architectures have accomplished the feature of enforcing dynamic security policies in an ultra-low latency interval of 1.8 milliseconds. This result is significant since it confirms the non-disrupting integration of ZTA security controls within real-time industrial processes where delays are unacceptable.

5.2. Adversarial Resilience:

Attack Success Rate (ASR) vs Penetration Testing Results To quantify the practical security benefits of ZTA, the adversarial resilience was measured using "Red Teaming" penetration testing data, simulating Advanced Persistent Threat (APTs) focused on lateral movement and data poisoning. Attack Success Rate (ASR) is a direct measure of the frequency with which malicious attempts are successful in breaching the system.[20]

Table V.2: Adversarial Resilience Metrics (2025 Penetration Testing)

Attack Vector	*Security Model*	*Attack Success Rate (ASR)*	*Implied Efficacy*
Data Poisoning	Baseline (No ZTA/PBSM)	64.8%	N/A
Data Poisoning	ZTA (Trust-Weighted)	7.4%	90%+ Reduction
Interception	Zero-Trust Routing (QKD)	Reduced by 97.2%	Near-absolute protection
Deepfake Phishing	AI-Enhanced ZTA	< 5% (95% Detection)	Highly effective mitigation

The simulation data illustrates an exaggerated difference between the traditional models and zero-trust architecture (ZTA). Federated IoT networks In federated IoT, a trust-weighted ZTA mechanism reduced the attack success rate (ASR) of data poisoning attacks by a significant margin (64.8) to a minute 7.4) percentage. Such a more than 90 percent

drop in breach success is a proof of the architectural effectiveness of the ZTA. The neutralization is brought out of micro-segmentation and regular scoring of trust which in effect eliminate the vulnerabilities of implicit trust exploited by adversaries to stretch sideways and carry out mass scale data distortion. Moreover, the AI-Enhanced ZTA had a detection rate of 95 percent in highly advanced deep-fake phishing attacks.

5.3. AI Policy Engine Efficacy and False Positive Control:

The Policy Engine is based on combined AI models, AE -LSTM, to compute dynamic trust scores. It can be analyzed that AIZTF was detected by the AI to be highly accurate with 96.8 percent. It is challenging to achieve high accuracy within a real-time operational setting and ensure it is not excessively blocked by legitimate traffic, though the AIZTF still managed to ensure a low False Positive Rate (FPR) of under 2.5 0. Such low FPR is paramount particularly in the context of Operational Technology (OT) that confirms that the complexity of continuous trust evaluation can be handled by AI without inappropriately penalizing valid network traffic and that policy changes can be quick and responsive.13

6. Discussion, Limitations, and Future Directions

6.1. Synthesis of Findings and Operational Feasibility Conclusion:

The statistical data shown in this work proves beyond doubt that ZTA is practically viable in autonomous IoT systems in the current era in technology. The lightweight, identity-based cryptography (Unified Enhanced FAST-SM9) at edge layer, and dynamic, predictive trust calculation (AE-LSTM) at Control Layer overcome the historical limitation imposed by the security-efficiency trade-off. Such architectural developments have demonstrated the ability to provide high security at low computation cost. As a result, the incorporation of ZTA is no longer bound by technical hardware capacity but is mostly about the strategic application as well as standardization of policies in the context of different OT/IoT ecology.

6.2. Critical Discussion of Limitations:

Despite the compelling performance and security metrics, specific operational challenges remain critical, particularly in sensitive environments.

The False Positive Paradox in Operational Technology (OT): While the low False Positive Rate (FPR) validates the AI's ability to balance security and performance, the need to apply it in safety-critical OT systems, however, is putting an extraordinarily new constraint on it, the reliability versus availability trade-off. System availability (zero downtime) is considered the most important requirement in OT and it takes precedence over confidentiality in some cases. The 2.5% false-positive rate, though statistically small in the conventional IT context, is an unreasonable risk in case it results in blocking of legitimate control traffic and can cause disastrous physical system downtime. This serves to point out the fact that the future requirement is a change in emphasis in favor of optimization of speed to the reliability of the trust calculation.

Legacy Integration and Centralized Bottlenecks :The FAST-SM9 performance benefits depend on the modern hardware that can support its lightweight protocols. In an industrial setting, legacy systems, also known as brownfield devices, represent a big installed base and might not have the necessary processing power (e.g., ARM CortexM0+ or better). To incorporate these outdated devices, ZT Gateways will have to intercept and apply policy externally. This requirement introduces a single, centralized, point of failure at the gateway and compromises the very philosophy of ZTA, which is all about decentralization, which is a weakness that can be exploited by more advanced enemies.

Evasion by Generative AI Threats: The high accuracy of behavioral analysis models (AE-LSTM) with a concerning 96.8 percentage of detection is bound to decrease over time owing to the quick development of adversarial techniques. According to surveys, Generative AI has the ability to automate the production of very advanced, polymorphic malware that will be resistant to traditional and behavioral analysis as they will be skillfully replicating legitimate device operations. The resulting development creates a requirement of these AI policy engine models under constant, dynamic updates, and a time-constrained challenge on the obtained detection accuracy.

6.3. Future Work

Judging by the quantitative validation of ZTA feasibility and the identification of the critical remaining constraints, future research needs to focus on the following points:

6.3.1. FPR Reduction in OT Systems: Special research is needed in order to develop hybrid trust models - that is, possibly a combination of behavioral analysis with very trustworthy physical layer security metrics - to reach an FPR acceptance below the 0.10 threshold requirements of life-critical OT systems1.

6.3.2. Decentralized Legacy Integration: New decentralized techniques to integrate brownfield devices need to be investigated that employ low-power and specialized hardware proxy agents at the local segment level to implement ZTA policy without mustering ZTA highly exploitable centralized ZT Gateways1.

6.3.3. Quantum-Resilient ZTA Development: Due to the use of high-level identity-based cryptography, there is a need to implement on-going testing and implementation of entirely post-quantum cryptographic primitives to maintain the long-term robustness of ZTA architectures to the eventual threat of quantum computing capabilities.6

7. Conclusion

This paper has presented detailed quantitative data to demonstrate that ZTA is no longer a speculative security mechanism, but a practically viable and a necessary framework to manage resilient autonomous IoT systems. The combination of modern protocols, especially the Unified Enhanced FAST-SM9 has achieved a breaking of the security-efficiency trade-off of the past, showing a 56.6% and 63.0% decrease in authentication latency and energy usage respectively over legacy PKIS. Moreover, the implementation of micro-segmentation and constant trust computation on behalf of ZTA is proved by the data of penetration tests, which demonstrates that the probability of adversarial breaches has decreased more than 90 percent in high-stakes federated settings. Although the underlying technological limitations have been eliminated, stability in the future, particularly in a safety-critical OT, would need a focused effort to optimize the models of trust and solve the False-Positive Paradox, leading to detection reliability of near-perfect.

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