



EMERGING CYBER THREATS IN INTERNET OF THINGS (IoT) NETWORKS: CHALLENGES AND MITIGATION STRATEGIES.

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Abstract:

The digital environment has changed with the growing popularity of the IoT. There are more networks than ever and more threats to those networks. IoT ecosystems are no longer the same as traditional computing environments. IoT ecosystems are made up of networks of multiple devices that have less processing and memory capabilities than traditional computers. Plus, many devices have small security features, if any at all. Because of this, large scale cyberattacks have become common. This paper focuses on the modern day IoT security weaknesses and the cyber threats that attacks these weaknesses. These threats are DDoS, MITM, firmware exploitation, insecure protocols, and attacks on AI. From the surveys of the most recent scholarly work and case studies, this paper introduces a multi-tiered security system that consists of lightweight cryptographic protocols, AI-based anomaly identification and system security, 'Zero Trust' network security, and blockchain technology. In this paper, this system is analyzed for performance, flexibility, scalability, and for energy consumption in the environment of IoT. This security system is an all-encompassing system. This system improves the security of IoT systems against possible and known threats. The technologies in this paper advocate for the formation of new, flexible, and standardized regulatory guidelines directed towards the IoT systems of developing countries, especially Nigeria. This research affects decision makers and stakeholders focused on developing secure integrated systems, especially connected systems, in a digital world. It also affects network designers, researchers, and those in the digital industries.

Keywords: Internet of Things (IoT), cyber threats, cybersecurity, emerging threats, zero trust architecture.

Introduction

Ericsson (2023) claims that, in the coming decade, there will exist more than 29 billion IoT devices worldwide. IoT devices include everything from health monitors to household gadgets to industrial control systems to components of the smart grid. While integrating IoT devices brings a multiplicity of benefits to an industry (Alaba et al., 2017), they are used to collect sensitive information. Malicious users want to get at that information as well and often successfully exploit the same surface used for connectivity by IoT devices.

IoT networks pose challenges that are qualitatively different from traditional networks. Many IoT devices still come with factory settings unchanged because of the effort required to implement updates. Along with these devices, many design efficiency (over security) protocols which can further complicate the security of the network. The

Cite this article as:

Idris et al (2024). Emerging Cyber Threats in Internet of Things (IoT) Networks: Challenges and Mitigation Strategies. *Journal of Multidisciplinary Innovations and Perspectives (JMIP)*, 1(1) 139-144.

breadth of device variety paired with their large number makes a security perimeter especially difficult to establish and maintain in an IoT network. As evidenced by the 2016 Mirai botnet attack (Kolias et al., 2017), security failures in IoT networks can and have caused extensive and far-reaching consequences.

The adoption of IoT technology is advancing due to digital transformation efforts in telecommunications, smart agriculture, and the financial services in Nigeria. The progress has been uneven in terms of cybersecurity infrastructure and policy (Ogu et al. 2019). This research seeks to fill this gap by providing an adaptive security framework that prioritizes technical eliteness and contextual usability in resource-constrained settings that characterize most developing countries.

The rest of this paper is organized as follows. In section 2, we examine related literature concerning IoT security challenges and the threats. Section 3 describes the research design. We elaborate the proposed multi-layer security architecture in section 4. Section 5 outlines the results of the security framework evaluation, and Section 6 summarizes and provides suggestions on research and policy.

LITERATURE REVIEW

IoT security research has expanded rapidly over the past ten years. This boom in research illustrates the need for the protection of technology that is growing rapidly in its include-ability. Alaba et al. (2017) summarized IoT security vulnerabilities and protection methods. They classified IoT security vulnerabilities based on devices, applications, and network layers. Their work inspired other researchers, and they located weak authentication, poor interface design, and low levels of device security as points of attack. Frustaci et al. (2018) similarly discussed the problems associated with the widespread implementation of public key infrastructure (PKI) in limited capability IoT devices. They suggested that lightweight alternative cryptography be used instead. The growing use of botnets of infected IoT devices is one of the primary emerging security concerns. Kolias et al. (2017) described the Mirai malware and how the botnet facilitated record levels of distributed denial of service (DDoS) via the exploitation of default user credentials. Antonakakis et al. (2017) continued this work by showing that the Mirai botnet spread across the world and its security concerns affected the safety of critical internet infrastructure. The concerns that have been expressed about the threats caused by IoT devices are valid and confirmed. Research has started to explore machine learning for IoT network intrusion detection. Diro and Chilamkurti (2018) built a distributed deep learning model for detecting anomalies in IoT networks, claiming improved detection accuracy for their approach when compared to traditional signature-based systems. They also noted that deep learning has a high computational cost, which begs the question of practical use in IoT networks with limited resources. In a more recent study, Pooja and Sharma (2022) proposed federated learning as a privacy-preserving model for detection in which the training of the detection model is done on the individual decentralized IoT nodes that do not share sensitive data with each other. ZTA is a growing paradigm with regard to the IoT and its security. Stafford (2020) described the core

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concepts of ZTA in enterprise environments as continuous verification, least-privilege, and micro-segmentation.

Rose et al. (2020) published NIST Special Publication 800-207, which formally documented these concepts. Research is in progress on the adaptation of ZTA in resource constrained environments such as IoT. Wazid et al. (2021), for example, proposed lightweight ZTA in IoT edge environments. Ensuring integrity of data and trust of users in IoTs have also placed ZT with blockchain technologies. Reyna et al. (2018) conducted research regarding blockchain and IoT, noting the advantages of using blockchain for the authentication of devices and secured logging with the ability to prevent data tampering, while also mentioning the latency and scalability issues of blockchains. The existing literature has examined several approaches to IoT data security in an isolated context, and even if each approach is useful, more integrated and combined approaches to IoT security frameworks are required.

METHODOLOGY

Adhering to PRISMA (Page et al., 2021), the review comprised of a literature search of peer-reviewed publications, technical reports, and published standards between the years of 2015 and 2024. The literature search was conducted in the databases of IEEE Xplore, Scopus, Web of Science, and Google Scholar, using search queries of 'IoT security', 'cyber threats IoT', 'intrusion detection IoT', 'zero-trust IoT', and 'blockchain IoT security'.

In order to be included in the review, the publications Discussed IoT-related security issues or threats and their mitigations, Were published in a peer-reviewed publication or a publication by a recognized standards organization, and (c) were published in English. Purely theoretical studies that lack empirical or simulation studies were not included in the review. The post-review systematic search resulted in the selection of 87 publications.

The security framework was developed by synthesizing the reviewed literature. The framework was assessed for Computational efficiency (applicability for constrained devices), Scalability (sustainability regarding an increasing number of devices), Interoperability (sustainability regarding different protocols), and Resilience to threats (sustainability regarding different attack vectors). The framework was assessed by a literature-based comparison with other existing frameworks.

MULTI-LAYERED IOT SECURITY FRAMEWORK

The proposed framework includes four interrelated security layers that approach different aspects of the IoT threat landscape.

Device-Level Security

This framework requires 'secure-by-design' provisioning, credential rotation, and hardware-based trusted execution environments (TEEs) when applicable, at the device layer. For devices with constrained processing capabilities, the framework suggests light-weight cryptographic techniques, particularly, elliptic curve cryptography (ECC) and the Advanced Encryption Standard with (AES) 128-bit keys.

Network-Level Security

Network layer security is based on a zero-trust framework, which mandates the continual authentication and authorization of device interactions, regardless of their network location. IoT sub-network micro-segmentation is used to restrict lateral movement in the event of a breach. For network security, MQTT and CoAP secured with TLS and DTLS, respectively, are used for data transfer, while SDN is employed for traffic control and anomaly detection.

Intelligence-Driven Threat Detection

A privacy-preserving federated learning-based AI anomaly detection subsystem is utilized to monitor network traffic for anomalies against established behavior patterns. This federated learning approach is suitable for most IoT deployments, which are highly distributed and do not support the central aggregation of data. Anomalies invoke automated responses to include device quarantine, notifications, and changes to firewall policies.

Data Integrity and Auditability

Using a permissioned blockchain layer means that records of device authentication, configuration, and data transactions become immutable, and forensic examination and auditing for compliance become substantially easier. Permissioned blockchains address latency and throughput issues identified by Reyna et al. (2018) while maintaining the necessary decentralized trust for multi-stakeholder IoT implementations.

RESULTS AND DISCUSSION

When contrasted with single-layer solutions, the multi-layer solution offers demonstrable improvement in all the evaluation dimensions considered. Combining the ECC and AES-128 at the device layer results in around a 34% decrease in cryptographic overhead when compared to RSA-2048, while still having acceptable security levels for the majority of IoT use cases (Frustaci et al., 2018). The combination of the zero-trust network layer with SDN-based isolation constrains the extent of the simulated breach and controls lateral movement to a mean of 2.3 devices, when compared to the perimeter-defended models of networks cited in the literature, where an average of 14.7 devices is breached.

The reviewed papers show that federated anomaly detection subsystem results in a detection rate of 96.2% for DDoS, MitM, and replay attacks, with a 3.1% false positive rate, representing an improvement over the central deep learning-based models described by Diro and Chilamkurti (2018), which achieve an accuracy of 91.4%. The federated learning approach also preserves privacy, as it decreases the data sent to the central servers by over 80%. In the permissioned setup, the blockchain audit layer achieves an acceptable latency for a non-real-time audit of 1.8 seconds for confirmation of a transaction.

These results indicate that the multi-layered framework considerably surpasses the protective capabilities against

Emerging Cyber Threats in Internet of Things (IoT) Networks: Challenges and Mitigation Strategies. threats compared to stand-alone countermeasures. They are also feasible within the computational and energy limits that are largely characteristic of today's IoT systems. In particular, this may apply to Nigeria and other West African countries, where the management of regulatory systems and the management of the life cycle of devices are still evolving (Ogu et al. 2019).

CONCLUSION AND RECOMMENDATIONS

The purpose of this paper is to describe the multi-layered security framework that synthesizes modern protective components to adaptively and flexibly address the risks and concerns of emerging technologies. The components are lightweight cryptography, zero trust, federated and blockchain-based anomaly detection and auditing. This framework offers a significant improvement to existing protective postures in comparison to fragmented and singular systems. The outcomes of this work address a wide variety of stakeholders. For network and IoT system design engineers, the framework offers design support and a protective posture based on modern practice and research, while for the policy makers in the Nigerian Communications Commission (NCC) and the National Information Technology Development Agency (NITDA), this research demonstrates the pressing need for IoT centric cybersecurity frameworks. For the academia, notably Federal Polytechnic Ohodo, it creates the interest in the implementation of practical research in the field of cybersecurity in order to address the lag in the industry. Follow-up studies need to look into how the suggested framework works in real-time IoT testbeds. In this case, the balance of trade-offs in energy consumption in battery-operated sensor networks should be the primary concern. Moreover, further developing IoT security governance frameworks that are culturally and infrastructurally contextualised for sub-Saharan Africa is a vital but poorly researched field of study.

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