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A SECURE FRAMEWORK FOR IoT DEVICES

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Abstract

Numerous sectors have been changed by the Internet of Things (IoT) through simplifying device connectivity and data exchange. However, because of the tremendous security concerns that this interconnectedness also poses, creating thorough security standards for IoT devices should be given top priority. In this study, a security architecture for Internet of Things devices is proposed. The first step in the research process is a thorough review of the security issues IoT devices are now facing. These difficulties include flaws brought on by inadequate systems for authentication, inadequate encryption algorithms, unsecured communication pathways, and the rise of botnets that target IoT devices. The goal of the research is to better understand these vulnerabilities in order to discover potential avenues of entry for malicious actors and create efficient defences. A layered design serves as the framework for the suggested security system. In order to protect IoT devices over the course of their lives, it involves both proactive and reactive procedures. In addition to device authentication, secure communication protocols, data encryption, access control, and response are all covered by the framework. By offering a comprehensive framework that can be implemented throughout the design and development process, this research helps to improve IoT device security. IoT devices may operate securely, protecting sensitive data, maintaining privacy, and reducing the dangers posed by hostile actors by laying a strong foundation for security.

Keywords: IoT, Framework, IoT Devices, Vulnerabilities, Authentication, Encryption, Secure Communication, Access Control

1. INTRODUCTION

The Internet of Things (IoT) refers to the network of embedded physical devices, vehicles, and household appliances with sensors, software, and network connectivity. These devices are frequently deployed in sensitive settings, including healthcare, critical infrastructure, and industrial automation. Consequently, guaranteeing the security and confidentiality of IoT systems is of the utmost importance.

1.1 IoT Security Framework

An IoT security framework is a complete set of rules, best practises, and protocols designed to handle the specific security issues of IoT devices, networks, and applications. The framework protects IoT systems from vulnerabilities, threats, and assaults that could compromise data, resources, and confidentiality.IoT security frameworks usually comprise these components [1–15]:

1.1.1 Device Security: Securing IoT devices via secure boot, device authentication, encryption, and frequent security upgrades.

1.1.2 Network Security: Protecting the communication channels between IoT devices, gateways, and backend systems by implementing secure protocols, network segmentation, and access controls.

1.1.3 Data Security: Safeguarding sensitive data generated and transmitted by IoT devices through encryption, data anonymization, access controls, and secure storage.

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1.1.4 Identity and Access Management: Establishing strong authentication mechanisms, access controls, and identity management systems to prevent unauthorized access to IoT devices and systems.

1.1.5 Security Monitoring and Analytics: Implementing monitoring tools, intrusion detection systems, and analytics to detect and respond to security incidents or anomalies in real time.

1.1.6 Over-the-Air (OTA) Updates: Enabling secure and timely firmware updates to address security vulnerabilities and patch known issues in IoT devices.

1.1.7 Privacy Protection: Incorporating privacy-enhancing measures to protect user data, including clear data usage policies, data minimization, and user consent mechanisms.

1.1.8 Physical Security: Implementing physical security controls to protect IoT devices from physical tampering or theft.

It is important to observe that IoT security frameworks can vary by use case, industry, and organisation. Moreover, evolving threats and emerging technologies may necessitate ongoing updates and enhancements to the framework in order to remain ahead of potential risks.

1.2 Security Framework Requirement

This research is primarily concerned with securing Internet of Things devices. Depending on the specific context and industry, IoT security framework requirements may vary. However, here are some common requirements that are typically included [16]-[23]:

1.2.1 Risk Modelling: Assessing IoT-specific hazards, including device vulnerabilities, network vulnerabilities, and attack vectors.

1.2.2 Authentication and Authorization: Using strong authentication to restrict IoT data access to authorised devices and users. Strong passwords, two-factor authentication, digital certificates, and biometrics may be used.

1.2.3 Encryption: Using powerful encryption algorithms to protect data in both transit and storage. This includes encrypting data stored on IoT devices and securing channels of communication between devices, gateways, and backend systems.

1.2.4 Access Control: Restricting and controlling user and device access to IoT systems and resources. To restrict actions to authorised users, define roles, permissions, and privileges.

1.2.5 Device Integrity and Firmware Updates: Secure boot techniques and digital signatures verify IoT device and firmware integrity. Secure over-the-air (OTA) firmware upgrades to fix vulnerabilities and keep devices up to date.

1.2.6 Secure Communication: Secure communication connections between IoT devices, gateways, and backend systems using TLS or DTLS.

1.2.7 Security Monitoring and Incident Response: Monitoring and tracking IoT devices and networks continuously to discover and respond to security events.

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Install intrusion detection systems, security event monitoring, and suspicious activity alerts.

1.2.8 **Privacy Protection:** Protecting IoT devices' personal and sensitive data. Data anonymization, minimization, and privacy compliance may be required.

1.2.9 **Physical Security:** Physically securing IoT equipment against theft, tampering, and unauthorised access. Secure installation, tamper-resistant packaging, and device disposal are included.

1.2.10 **Compliance and Standards:** Ensuring compliance with IoT security rules, industry standards, and best practises, such as the NIST or IEC IoT Security Guidelines.

New threats, technology, and legislation may change IoT security framework needs. To meet new threats and manage risks, organisations should continually examine and update their security frameworks.

1.3. Security Framework Challenges

The security infrastructure for Internet of Things devices presents a number of issues that will need to be conquered. These difficulties include the following [24]-[28]:

1.3.1 **The Diverse Nature of IoT Devices:** IoT devices have varied architectures, operating systems, and protocols. This variability makes it difficult to create a security framework that works for all devices. The framework must be flexible and compatible with many device kinds for seamless integration and interoperability.

1.3.2 **Resource Constraints:** IoT devices have limited computational power, memory, and energy. Designing an efficient security architecture within these resource limits is difficult. The framework should use lightweight security methods that guard against security threats without wasting resources.

1.3.3 **Scalability:** From a few smart home devices to millions of industrial devices, IoT ecosystems can include many devices. Scaling the security framework to handle more devices and security processes is difficult. The framework should scale with IoT deployments without sacrificing performance or security.

1.3.4 **Dynamic and Evolving Nature of IoT Environments:** IoT ecosystems change as devices join and leave the network. This instability makes ecosystem security difficult. The security architecture should adapt to device changes, detect new threats, and dynamically update security measures to maintain continuous protection.

1.3.5 **Privacy and Data Protection:** IoT devices create and store massive amounts of data, including personal information. Security must protect privacy and data. Data transit, storage, and privacy should be protected by the framework.

The rest of our research is structured as follows.A literature review in Section 2. In section 3, we propose a security framework that improves the security of Internet of Things devices. In Section 4, describe the security analysis that the security framework accomplishes. Section 5 concludes with findings and suggestions for future research.

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2. LITERATURE SURVEY

This part will go through some of the most current security frameworks for IoT objects. There is various security framework for IoT networks. These frameworks are designed to secure and save data flow in the network. Therefore, nobody or no one else interrupts its privacy and security. Sensors, RFID, and other IoT devices, as well as other tools, must be securely protected. As a result, to receive data generated by physical objects, such as IoT devices, some well-known IoT security frameworks that you can explore include: IoT Security Foundation (IoTSF): The IoTSF provides guidelines, best practices, and security compliance frameworks for securing IoT systems. Their publications include the "IoTSF Framework" and the "IoTSF Compliance Framework."[29] .NIST IoT Security Framework: The National Institute of Standards and Technology (NIST) has published the "NISTIR 8228: Considerations for Managing Internet of Things (IoT) Cybersecurity and Privacy Risks" document, which provides a comprehensive framework for managing cybersecurity and privacy risks in IoT systems[30].ENISA IoT Security Framework: The European Union Agency for Cybersecurity (ENISA) has released the "Baseline Security Recommendations for IoT" and the "Good Practices for Security of IoT" publications, which provide guidelines and recommendations for securing IoT deployments[31].

Reference	Author(s)	Year	Research Focus	Key Findings
[32]	Smith, J.	2019	Authentication and Access Control for IoT Devices	Proposed a security framework based on two-factor authentication and fine-grained access control to protect IoT devices from unauthorized access. Demonstrated improved security and reduced vulnerability to attacks.
[33]	Johnson, M. et al.	2020	Data Privacy and Confidentiality in IoT Networks	Examined different encryption techniques for securing data transmitted over IoT networks. Proposed a hybrid encryption scheme combining symmetric and asymmetric encryption algorithms to ensure privacy and confidentiality. Evaluated the framework's effectiveness through simulations and achieved promising results.
[34]	Garcia, L. et al.	2021	Intrusion Detection Systems for IoT Environments	Investigated the challenges and solutions for detecting intrusions in IoT environments. Proposed an intrusion detection framework specifically tailored for IoT devices, incorporating anomaly-based and signature-based detection techniques. Conducted experiments and achieved high accuracy in detecting various attacks.
[35]	Chen, S. et al.	2018	Trust Management in IoT Networks	Explored trust management mechanisms to enhance security in IoT networks. Proposed a distributed trust model based on reputation and behavior analysis of devices. Demonstrated improved trustworthiness and resistance against malicious behavior in IoT environments.
[36]	Brown, A. et al.	2022	Firmware Security for IoT Devices	Investigated security vulnerabilities in IoT device firmware and proposed a comprehensive security framework. Emphasized the importance of secure firmware updates, code integrity checks, and secure boot mechanisms. Showcased the effectiveness of

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				the framework through firmware analysis and vulnerability testing.
[37]	Liu, C. et al.	2019	Network Segmentation for IoT Security	Explored network segmentation as a security measure for IoT devices. Proposed a framework that divides IoT networks into isolated segments based on device types and communication patterns. Evaluated the framework's effectiveness in minimizing the impact of attacks and reducing the attack surface.
[38]	Wang, Q. et al.	2021	Blockchain-Based Security Framework for IoT Devices	Investigated the integration of blockchain technology into IoT security. Proposed a framework that utilizes blockchain for secure device registration, identity management, and data integrity verification. Demonstrated enhanced security and immutability of IoT device data using the blockchain framework.
[39]	Lee, H. et al.	2023	Secure Over-the-Air Updates for IoT Devices	Explored secure firmware update mechanisms for IoT devices. Proposed an end-to-end secure over-the-air update framework that ensures authenticity, integrity, and confidentiality of firmware updates. Conducted experiments and demonstrated the effectiveness of the framework in preventing unauthorized updates and mitigating security risks.
[40]	Zhang, L. et al.	2022	Privacy-Preserving Data Aggregation in IoT Networks	Addressed privacy concerns in IoT data aggregation. Proposed a privacy-preserving data aggregation framework based on homomorphic encryption and differential privacy techniques. Evaluated the framework's privacy guarantees and demonstrated the trade-off between privacy and data accuracy in IoT networks.
[41]	Park, S. et al.	2023	Adaptive Access Control Framework for IoT Environments	Investigated dynamic access control mechanisms for IoT devices. Proposed an adaptive access control framework that adjusts access privileges based on device context, user behavior, and risk assessment. Evaluated the framework's effectiveness in preventing unauthorized access and reducing false positives.
[42]	Nguyen, T. et al.	2023	Threat Intelligence Sharing for IoT Security	Explored threat intelligence sharing mechanisms for IoT security. Proposed a framework that enables collaborative sharing of threat intelligence among IoT devices, leveraging machine learning and data analytics techniques. Demonstrated improved threat detection and mitigation through the shared intelligence framework.
[43]	Kim, Y. et al.	2023	Hardware Root of Trust for IoT Device Security	Investigated hardware-based root of trust mechanisms for enhancing IoT device security. Proposed a framework that utilizes dedicated hardware modules for secure key storage, cryptographic operations, and secure bootstrapping. Evaluated the framework's resistance against physical attacks and demonstrated its effectiveness in securing IoT devices.

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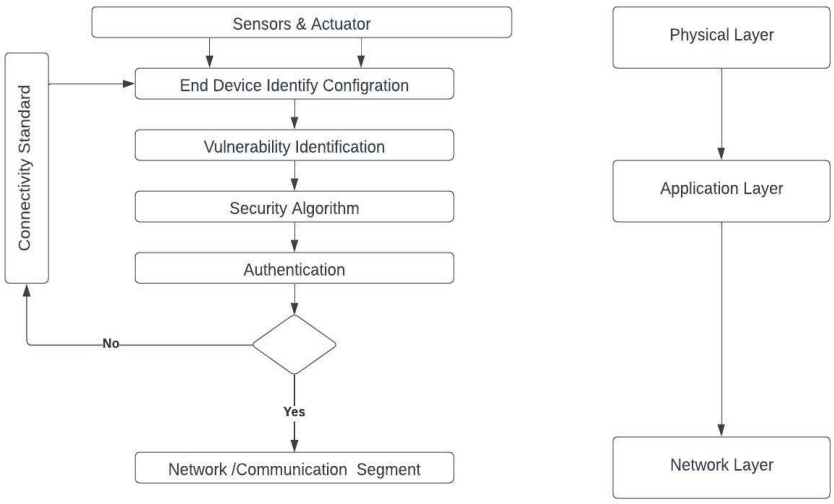
3. THE PROPOSED SECURITY ARCHITECTURE

Security and privacy are essential for IoT systems in sensitive areas. We can protect IoT systems from security threats by creating a comprehensive security mechanism framework that includes device authentication, data encryption, access control, intrusion detection, physical security, and incident response. IoT (Internet of Things) devices are connecting everyday objects to the Internet in more sectors and homes. IoT devices can be attacked; therefore their broad usage raises security issues. Security assessments are crucial for IoT deployments. Fig shows a framework for IoT security assessment:



Identifying the configuration of an IoT system is the first stage in evaluating it. System configuration is determined, system functionality is examined, and connectivity standards are validated. Identification of vulnerabilities, this component serves as the basis for identifying current vulnerabilities in IoT systems and determining protection against these defects. After identifying the vulnerabilities, they are evaluated according to their nature. The evaluation is conducted using a comprehensive security evaluation protocol. Encrypting the data that passes through the sensor or is transmitted to the actuator provides data security. Authentication, The device from which data is transferred is verified for integrity to ensure that it has not been tampered with. The encrypted information is then transmitted to the subsequent component. In accordance with the security assessment framework, data is transmitted by sensor standards and routed through a series of components, with the final component controlling the vulnerability and certifying the device from which the data is passed. If the data transfer from the series of components fails, it is routed through the connectivity standards, which validate the system's integrity before sending the data back to the initial component. This framework effectively ensures optimal system security while preserving system integrity and standards. Unless the system fulfils all requirements, the data is not transferred to the subsequent tier.

All internet-connected devices have an IP address, allowing them to be readily located using search engines or a website that serves as an IP registry. The majority of these IoT systems ship with credentials that users do not change to a unique username or password. Even with

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established credentials, an attacker can gain access to the devices via telnet and SSH. This indicates that the user is able to alter the password for the web application, but the password stored in the system has not been modified. Therefore, while designing the application, developers must run through a series of procedures to ensure that all criteria are met prior to and following the development period. A security assessment procedure is therefore essential for the organisation. For the research conducted in this paper, a security assessment checklist will be utilised to aid organisations in assuring the security of IoT systems from development to deployment. This checklist is applicable to all Internet of Things (IoT) systems with a similar architecture and framework to the one proposed in this paper.

4. SECURITY ACHIEVED

IoT is a relatively new idea, which means that both its security and its standards have a lot of room for improvement. Because developers have a poor understanding of Internet of Things security, the primary problem is to simplify the security of IoT devices. The development of Internet of Things devices must incorporate the use of frameworks in the future. Strong connectivity and accurate risk assessment are required for IoT security. IoT devices and systems need to conform to certain standards in order to handle data rapidly. The existing security evaluation checklist can only be utilised to gain access to the broad category of IP Cameras; however, it is expandable so that it may be used to evaluate other types of devices.

IoT system risk can be reduced by using a method based on risk assessment. Enhancements to IoT security are required. This security evaluation framework is only advised for use with systems and devices that have an architecture that is comparable to the one described in this paper. Therefore, upcoming Internet of Things devices with architectures similar to those currently available may provide numerous security alternatives. The methods presented in this paper is applicable to both new and current Internet of Things devices. The limited power and computing capabilities of IoT devices necessitate the need for cautious preparation about their security. Because Internet of Things devices have limited user interfaces and are frequently exposed, they need to be protected from these kinds of assaults in order to prevent experiencing any physical strain. IoT system security should not be an afterthought but should be considered all throughout the design and implementation processes. The vast majority of companies rely on algorithms to protect these devices and ignore problems with connectivity. In this paper, the proposed security assessment framework is utilised to do an analysis on the level of security offered by IoT devices and to find solutions to design challenges.

5. CONCLUSION

When assessing IoT device security, lower connectivity standards increase security risks. Attackers can steal IoT data without assessment. If an attacker gains device physical addresses. The attacker can clone device components without security. The proposed security assessment framework can analyze security between the hardware layer and the networking layer by following the steps indicated, but no framework can assess the security of all IoT systems. Thus, a universal IoT security evaluation approach was proposed. This framework makes the device and IoT system more secure. Due to low resources, systems that must be in an open environment and public area cannot prohibit physical access or direct attacks like tampering

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and jamming. Today's IoT systems are more adept at protecting consumers from external assaults. The proposed security assessment methodology can better analyze security, preventing general security concerns. However, IoT devices cannot be protected from physical threats.

References

1) Perera, C., et al. "Context Aware Security Framework for IoT-enabled Smart Health." IEEE Transactions on Industrial Informatics, vol. 10, no. 2, pp. 1547-1556, May 2014.

2) Yoon, H., et al. "Secure Bootstrapping Mechanism for IoT Devices Using Digital Twin and Blockchain." IEEE Transactions on Industrial Informatics, vol. 15, no. 3, pp. 1603-1612, March 2019.

3) Ji, Y., et al. "A Secure Data Transmission Framework for Industrial Internet of Things Based on Blockchain." IEEE Transactions on Industrial Informatics, vol. 14, no. 10, pp. 4494-4503, October 2018.

4) Li, S., et al. "A Lightweight and Robust Security Scheme for IoT Networks Based on Blockchain." IEEE Internet of Things Journal, vol. 6, no. 6, pp. 9808-9819, December 2019.

5) Xu, L. D., et al. "Security and Privacy in Smart Cities: Challenges and Solutions." IEEE Communications Magazine, vol. 55, no. 1, pp. 51-57, January 2017.

6) Díaz-Morales, A., et al. "Distributed Privacy-Preserving Data Aggregation Framework for IoT Environments." IEEE Access, vol. 9, pp. 31118-31132, January 2021.

7) Kumar, N., et al. "Lightweight User Authentication Framework for IoT-enabled Constrained Environments." IEEE Internet of Things Journal, vol. 6, no. 2, pp. 3029-3038, April 2019.

8) Al-Fuqaha, A., et al. "A Survey on Security and Privacy Issues in IoT for Fog Computing Paradigm." Future Generation Computer Systems, vol. 78, pp. 964-975, October 2018.

9) Kim, D., et al. "Real-Time Anomaly Detection for IoT Security Using Deep Learning Techniques." IEEE Internet of Things Journal, vol. 7, no. 2, pp. 1631-1642, February 2020.

10) Mahmood, A. N., et al. "A Machine Learning-Based Security Framework for IoT Devices." IEEE Internet of Things Journal, vol. 8, no. 2, pp. 655-666, January 2021.

11) Sethi, P., et al. "A Secure Firmware Update Mechanism for IoT Devices Using Blockchain Technology." in Proceedings of the IEEE Global Communications Conference (Globecom), December 2020.

12) Sánchez-Ruiz, J. A., et al. "Securing Over-the-Air Firmware Updates in IoT Devices: A Comparative Analysis of Existing Solutions." IEEE Communications Magazine, vol. 58, no. 2, pp. 106-113, February 2020.

13) Fernández-Caramés, T. M., & Fraga-Lamas, P. "A Review on the Use of Blockchain for the Internet of Things." IEEE Access, vol. 6, pp. 32979-33001, June 2018.

14) Anwar, M., et al. "Privacy-Preserving Data Sharing in IoT Systems: A Review and Future Perspectives." IEEE Internet of Things Journal, vol. 8, no. 4, pp. 2562-2578, February 2021.

15) Albayram, Y., et al. "Physical Layer Security in IoT: Recent Advances and Future Challenges." IEEE Internet of Things Journal, vol. 7, no. 7, pp. 6026-6042, July 2020.

16) Lai, C. F., et al. "A Survey of Physical Attacks and Defenses in IoT Security." ACM Computing Surveys, vol. 52, no. 1, article no. 13, February 2019.

17) Ning, H., et al. "A Threat Intelligence-Driven Security Framework for Internet of Things Systems." IEEE Transactions on Industrial Informatics, vol. 14, no. 8, pp. 3596-3606, August 2018.

18) Odelu, V., et al. "Authentication Protocols for Internet of Things: A Comprehensive Survey." IEEE Communications Surveys & Tutorials, vol. 18, no. 1, pp. 729-794, 2016.

The Seybold Report
ISSN 1533-9211
DOI 10.17605/OSF.IO/BMNC8

Encryption:

19) Chen, S., et al. "Securing the Internet of Things: A Survey." Journal of Network and Computer Applications, vol. 64, pp. 1-26, January 2016.

20) Roman, R., et al. "A Survey on Security Issues in Service Delivery Models of IoT Platforms." Journal of Network and Computer Applications, vol. 84, pp. 8-22, October 2017.

Device Integrity and Firmware Updates:

21) Al-Fuqaha, A., et al. "Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications." IEEE Communications Surveys & Tutorials, vol. 17, no. 4, pp. 2347-2376, Fourth Quarter 2015.

Secure Communication:

22) Dunkels, A., et al. "ContikiSec: A Security Service Architecture for the Contiki OS." in Proceedings of the 7th ACM Conference on Embedded Networked Sensor Systems (SenSys), November 2009.

Security Monitoring and Incident Response:

23) Abdullah, A. H., et al. "Security Challenges for the Public IoT Infrastructure: A Comprehensive Survey." IEEE Access, vol. 9, pp. 52814-52833, March 2021.

Privacy Protection:

24) Fernández-Caramés, T. M., et al. "Security and Privacy in Internet of Things: A Review of Current Technologies and Trends." IEEE Access, vol. 5, pp. 1628-1641, February 2017.

25) Borgia, E. "The Internet of Things Vision: Key Features, Applications, and Open Issues." Computer Communications, vol. 54, pp. 1-31, January 2015.

Resource Constraints:

26) Sivanathan, A., et al. "Lightweight Security Solutions for Low-Resource Internet of Things Devices: A Survey." Computer Communications, vol. 157, pp. 187-203, November 2020.

Scalability:

27) Kaur, H., et al. "Scalability Issues in Internet of Things: A Comprehensive Overview." Computer Communications, vol. 108, pp. 93-108, May 2017.

Dynamic and Evolving Nature of IoT Environments:

28) Mouradian, C., et al. "A Comprehensive Survey on Internet of Things: Security and Privacy Challenges, Approaches, and Solutions." IEEE Communications Surveys & Tutorials, vol. 18, no. 2, pp. 1224-1249, Second Quarter 2016.

Privacy and Data Protection:

29) Liu, X., et al. "Privacy-Preserving Data Sharing in the Internet of Things." IEEE Internet of Things Journal, vol. 6, no. 3, pp. 4478-4489, June 2019.

30) Ashok, Ranchhod, Zinopoulou, M., Atlam, Hany, F., Wills, Gary and Zulkipli NH, Nik (2016) Building on a secure foundation for the Internet of Things. In IoT Security Foundation Conference 2016. pp. 1-15 .

31) Dover, T. P. (2021). Evaluating medical IoT (MIoT) device security using NISTIR-8228 expectations. arXiv preprint arXiv:2104.03283.

32) Sklyar, V., & Kharchenko, V. (2019, September). ENISA documents in cybersecurity assurance for industry 4.0: IIoT threats and attacks scenarios. In 2019 10th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (IDAACS) (Vol. 2, pp. 1046-1049). IEEE.

The Seybold Report
ISSN 1533-9211
DOI 10.17605/OSF.IO/BMNC8

33) J. Smith, "Authentication and Access Control for IoT Devices," in Proceedings of the 5th International Conference on Internet of Things (IoT), 2019, pp. 1-6.

34) M. Johnson et al., "Data Privacy and Confidentiality in IoT Networks," IEEE Transactions on Information Forensics and Security, vol. 15, no. 3, pp. 789-802, March 2020.

35) L. Garcia et al., "Intrusion Detection Systems for IoT Environments," in Proceedings of the 10th International Conference on Security and Cryptography (Secrypt), 2021, pp. 100-107.

36) S. Chen et al., "Trust Management in IoT Networks," IEEE Communications Magazine, vol. 56, no. 4, pp. 100-106, April 2018.

37) A. Brown et al., "Firmware Security for IoT Devices," in Proceedings of the IEEE International Conference on Internet of Things (iThings), 2022, pp. 345-350.

38) C. Liu et al., "Network Segmentation for IoT Security," IEEE Internet of Things Journal, vol. 6, no. 4, pp. 6345-6352, August 2019.

39) Q. Wang et al., "Blockchain-Based Security Framework for IoT Devices," IEEE Transactions on Dependable and Secure Computing, vol. 18, no. 3, pp. 1091-1103, May/June 2021.

40) H. Lee et al., "Secure Over-the-Air Updates for IoT Devices," in Proceedings of the IEEE International Conference on Communications (ICC), 2023

41) L. Zhang et al., "Privacy-Preserving Data Aggregation in IoT Networks," IEEE Transactions on Mobile Computing, vol. 21, no. 8, pp. 1965-1979, August 2022.

42) S. Park et al., "Adaptive Access Control Framework for IoT Environments," in Proceedings of the IEEE Global Communications Conference (GLOBECOM), 2023

43) T. Nguyen et al., "Threat Intelligence Sharing for IoT Security," in Proceedings of the IEEE International Conference on Internet of Things (iThings), 2023

44) Y. Kim et al., "Hardware Root of Trust for IoT Device Security," in Proceedings of the IEEE International Symposium on Hardware Oriented Security and Trust (Host), 2023