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AI-POWERED KEY DISTRIBUTION MECHANISM FOR IOT SECURITY

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ABSTRACT

One of the many problems IoT has brought is secure key distribution for connected devices. However, it is growing rapidly, which brings with it many security challenges. In this research, an adaptive cryptographic protocols based key distribution mechanism powered by AI is presented to improve the IoT security. Using lightweight encryption algorithm like PRESENT and SIMON, which has very low computational overhead, the proposed system also has compatibility with the resource constrained IoT devices. Moreover, a new dynamic key management framework using machine learning models, is used in order to monitor and prevent potential security threats in real time. Blockchain technology is integrated further to strengthen the system as it enables decentralized trust and secure key exchange in distributed networks. Experimental evaluations show that the performance is better in terms of energy efficiency, latency reduction and resistance against cryptographic attacks as compared to the traditional key management schemes. Furthermore, the proposed solution tackles scalability issues by using clustering techniques to deal with large scale of IoT networks.

With this AI driven method, adaptive learning models are built, which adaptively optimize key distribution strategies continuously and dynamically divert key distribution capability in accordance with the changing circumstances of the network as well as the changing patterns of threat. With incorporating the recent cryptographic protocols,

blockchain technology as well as machine learning, this framework forms a powerful solution to bolstering IoT security.

Keywords: IoT security, key distribution, lightweight cryptography, blockchain, machine learning, PRESENT cipher, SIMON cipher, adaptive security, decentralized trust, dynamic key management.

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I. INTRODUCTION

The Internet of Things (IoT) devices proliferated rapidly, bringing about enormous impact on the modern infrastructure with real time wireless communication among the smart homes, the healthcare and industrial automation. However, exponential growth of the network has led to serious security concerns, especially in the key distribution mechanisms for resource constrained devices [1]. In IoT environment, traditional cryptographic protocols generally fail to find the right balance among security, performance and scalability. As a result, ensuring secure key exchange and lightweight encryption is still a big challenge [4]. In relation to lightweight block ciphers, recent advances in such block ciphers as PRESENT and SIMON have shown promising abilities to encrypts at low overheads that make them suitable for IoT networks. Moreover, blockchain as a solution for decentralized trust and tamper proof key management has also been found [6].

However, despite such advancements, currently available key distribution frameworks are still vulnerable to evolving types of attacks e.g. side channel attacks [2] and network intrusion attacks [1]. Furthermore, key generation in dynamic large scale networks is a challenge in efficient resource utilization [3]. In order to fill in this gap, this research indicates that the union of lightweight cryptography, machine learning and blockchain technology can be used to build an AI based key distribution mechanism to enhance IoT security. The main goal is to improve the resilience of key distribution, optimize the network efficiency, and reduce the energy consumption as well as to provide strong defense against security threats [6]. This is a novel approach towards IoT security to overcome the existing challenges and to enhance secure communication among the interconnected devices.

II. LITERATURE SURVEY

Secure key distribution mechanisms have been studied in many researches to solve IoT security problems. One of such research is that lightweight encryption algorithm, efficient key management framework, emerging technologies, etc can be put into use to increase security in a resource constrained IoT environment. Few lightweight ciphers, like PRESENT and SIMON, have been proved to be secure in IoT devices without performance degradation [7, 8]. Moreover, AI's models have demonstrated the abilities to detect a malicious activity, thus updating the security protocols dynamically [6]. However, the security, scalability, and real time performance still has gaps to be balanced. The decentralized nature of blockchain architecture has turned out to be a robust solution to secure key exchange, but its integration with lightweight cryptography has not been explored yet [6]. The following sub-sections delve into key areas of related research.

1. Lightweight Cryptography for IoT Security

Ensuring secured communication in the resource constrained environment is greatly dependent on the lightweight cryptographic algorithms. It is one of the ciphers, which have been widely adopted because of its minimal hardware requirements and strong resistance to linear and differential cryptanalysis [7]. Another good example is the SIMON cipher, which similarly provides a flexible structure for the purpose of securing IoT devices with limited processing capabilities [8]. In the research by Bogdanov et al., they introduced the PRESENT cipher as a very efficient block cipher for low power applications, while also providing improved security at minimal latency [8]. In [7], another study suggested a flexible implementation of lightweight ciphers to improve the performance in wireless sensor networks (WSNs). Although lightweight ciphers have the strengths, they are restricted in dynamically responding to changes of threats and the adaptive learning model needs to be integrated.

2. Machine Learning for Adaptive Security

For achieving the secure world, machine learning models have been helpful in predicting different pattern of attacks and dynamically modulating the security protocol. [6] In [6], Panda et al. introduced as AI based framework using anomaly detection method to detect suspicious behavior in IoT networks. The detection rates were increased while false positives were kept minimal. Another study also examined reinforcement learning models that can be used to optimize cryptographic key exchange protocols so as to improve both security and performance in IoT environments [2]. AI security models are especially useful in cases of identifying zero day attacks and adaptive security in imprecountably conditions of the network.

Nevertheless, putting the ML model to work with lightweight encryption systems efficiently and with low resource consumption is not straightforward.

3. Blockchain for Secure Key Exchange

The blockchain technology has appeared as a credible solution to secure key distribution in the IoT environment. Panda et al. suggested the authentication framework based on blockchain that ensures tamper proof key management over the distributed network [6]. So, this approach takes advantage of smart contracts to make secure key exchanges automatically, thus reducing man in the middle attack risks. This concept was expanded by Alshammari et al. through utilizing the blockchain with the session based communication models to enhance the scalability of the massive IoT networks [3]. Nevertheless, blockchain and its implementations impose computational overhead that makes it less adopted by power constrained IoT devices, calling for efficient implementations.

4. Energy-Aware Security Solutions

Key management schemes should be energy efficient to prolong the lifespan of battery powered IoT devices. In [4], Messai and Seba proposed EAHKM+, which is a framework for secure communication based on clustering to minimize energy consumption with security. This is a hierarchical key exchange model applied for reducing the communication overhead in the dense IoT networks. For example, Sadhu et al. presented energy optimized cryptographic framework for low resource device, for which security and power efficiency are balanced [9]. Sustainable IoT deployments in large scale are only possible when these energy aware techniques are applied.

5. Dynamic Key Management Frameworks

The dynamic key distribution frameworks help in improving the resilience of the IoT network through the frequent update of the cryptographic keys according to the evolving threats. In [5], Mesmoudi et al. proposed a smart key management scheme (SKWN) that allows the regeneration of session keys in dynamic time based on the real time of network conditions, and makes it resistant to side channel attack. Using this approach, it employs AI-driven prediction models in order to enhance adaptive security mechanisms. Gautam and Kumar also studied scalable key distribution protocols that can handle key exchange efficiently in distributed IoT architectures with better security but no degradation in performance [10]. Yet, dynamic frameworks integration with current IoT protocols is yet to be implemented seamlessly.

III. MATERIALS AND METHOD

A key distribution mechanism based on the usage of lightweight cryptography, machine learning models and blockchain technology is proposed and the usage of AI in this mechanism can improve the security of IoT. The hardware and software requirements, implementation strategy and experimental setup for real time evaluation of the proposed system are outlined in this section.

The work was implemented on a Raspberry Pi 4 Model B equipped with a 1.5 GHz quad core ARM Cortex-A72 processor and 4 GB of RAM. This hardware was picked to mimic resource constrained IoT devices in the real world deployments. Furthermore, the ESP8266 microcontroller was used to simulate endpoints in the network that need to communicate securely. Different sensors and actuators were integrated with these hardware components to create a realistic IoT environment. The system used Mosquitto MQTT broker to manage lightweight communication between nodes and to scale the key exchange operations [1].

For algorithm development, the implementation of the software side used Python, and NumPy, TensorFlow and Scikit-learn were used to build machine learning models for adaptive security. The cryptographic protocols PRESENT and SIMON were integrated using custom built encryption modules optimized for performance [7] [8]. Hyperledger Fabric was used to develop the blockchain layer for secure and tamper proof key exchange across the distributed IoT nodes [6]. To automatically distribute the key and dynamically change the way the security protocols are handled when threat is identified, smart contracts were deployed.

The machine learning part was trained on a dataset with simulated attack pattern and network behavior derived from real world IoT traffic logs. The material was used to identify anomalies by combining decision trees, k-nearest neighbors, and deep neural network ensemble model for better accuracy [6]. During training phase, the data preprocessing is done to normalize the features of the network traffic, while iterative model refinement is done to improve the detection performance.

The setup of the experiment was to position multiple IoT nodes in a controlled environment under realistic network conditions. Encrypted packets were dynamically exchanged using session keys generated between two nodes by assigning each node a unique identifier. The system was evaluated under several loads on the network, attack scenarios and latency conditions to determine its scalability and robustness. To ensure that cryptographic operations were not using too much power, the energy consumption was measured using the INA219 current sensor module [4]. The security performance was measured through the key

compromise rates and the false positive detection metrics, which was analyzed using the timestamped message exchanges to monitor the key distribution latency.

Because of that, the number of confirmed transactions per second (TPS) was registered under different loading conditions to check out the blockchain performance. This was a key assessment that made it possible to determine whether the blockchain framework could support secure key distribution without introducing excessive delays in the network [6]. Furthermore, clustering based network topology optimizations have been introduced to reduce redundant communication overhead in the large scale deployment [3] for energy efficiency.

For the purpose of data collection, throughout the experiment packet flows, key exchange sequences and power consumption metrics were monitored. The performance improvements in regard to reduction in latency, encryption overhead, and key compromise rates were assessed based on the collected data points. The proposed system was compared with the existing key distribution frameworks and it was found that it reduced the latency by 32% and increased the energy efficiency by 27% and still maintained the robust security against the replay attack, eavesdropping, and side channel threats [5]. The machine learning models integration improved this system's threat adaptation technique and it could detect threats with 89% accuracy and very little false positives for them [6].

The proposed methodology was successful in integrating lightweight cryptography, adaptive machine learning models, and blockchain based security into each other thereby tackling the limitations that exist in IoT security frameworks. This proposed solution reduces the latency, enhances the power efficiency, and makes it scale; it offers us the chance to implement this in the secure IoT networks in the real world. Refinements of the system's scaleability by reducing blockchain overhead and the expansion of the machine learning models to catch more sophisticated patterns at work and in the various other IoT ecosystems is something that can be done in the future.

IV. RESULTS AND DISCUSSION

On the top of that, the proposed AI powered key distribution method was implemented in real time using Raspberry Pi 4 and ESP8266 microcontrollers as resource constrained IoT devices. Security performance, latency, energy efficiency, and scalability were used to analyze the experimental outcomes. Via a comparative study with the existing approaches, it was shown

that there is a significant enhancement of the key distribution effectiveness and system adaptability.

1. Security Performance and Threat Mitigation

Finally, the resistance of the system to the common attacks faced in IoT systems was assessed such as replay attacks, eavesdropping, and key compromise tries. It was shown that the integrated PRESENT and SIMON lightweight encryption [7] [8] were resistant against cryptanalytic attack but provided similar degree of security compared to the traditional encryption with much smaller computational overhead. In addition to this, the machine learning model used for anomaly detection had an accuracy of 89% to detect malicious traffic patterns compared to the conventional static security models [6]. In this way, this adaptive security mechanism can remarkably reduce zero day attack through dynamically revising key exchange protocols according to new threats while compared to traditional key management mechanisms [2].

The system was accordingly designed to refresh session keys dynamically in real time upon detecting suspicious packet sequences so as to prevent replay attacks in real time testing. The blockchain technology was used further to provide enhanced security as an immutable record of key exchange transactions was established, thereby reducing the possibility of key compromise in a multi session communication environment [6]. A combination of AI driven anomaly detection, lightweight cryptography and combination of blockchain solutions proved superior resilience against the network intrusions than the current static network security models [5].

2. Latency and Communication Overhead

System performance was evaluated with the key distribution latency as a crucial metric. Given the efficient clustering techniques for node communication, the solution proposed are able to reduce latency by 32% compared to conventional key exchange frameworks [3]. These new session keys were generated by the dynamic key regeneration strategy in order to significantly reduce the redundant communication overhead, when it was ensured that compromised session keys were revoked and newly generated keys were created immediately. This helped in minimizing the network congestion and hence, improve the real time performance in dense IoT networks.

Experimental results also showed that the proposed system has approximately an average latency of 120 ms for carrying out key exchanges in generic network conditions. Latency marginally increased to 185 ms under peak traffic condition, which is still within the

acceptable range required for IoT applications. For instance, response times of the proposed system were improved compared to traditional frameworks that experienced latency spikes greater than 300ms. Furthermore, the proposed system was more stable. The efficient integration of blockchain based smart contracts that automated secure key exchange transactions with very small delay [6] was attributed to this improvement.

3. Energy Efficiency and Resource Optimization

Particularly, energy efficiency was a great focus to enable sustainable deployment in resource-constrained IoT scenarios. In the proposed framework, the clustering based communication model effectively minimized the unnecessary data transmission of the data, which resulted in a 27% reduction in power consumption as compared to the conventional key management approaches [4]. Additionally, the PRESENT and SIMON ciphers achieved improved energy efficiency by keeping the computational complexity minimal and still secure data exchange [7], [8].

The power consumption of the system was measured using the INA219 current sensor and it remained more or less constant at an average of 0.85W under normal conditions and peaked at 1.2W under heavy traffic scenarios. It has shown great improvements in power efficiency that will prolong device operation in battery powered IoT environments. The system succeeded in countering the energy constraints of the IoT device and resided behind the energy limitations by minimizing the cryptographic calculations and exploiting lightweight protocols.

4. Scalability and Network Performance

To assess the scalability of the system, the system was scaled up and deployed to conduct key exchange among 50 interconnected nodes in a simulated smart environment to simulate a large-scale scenario. By clustering devices at various communication pattern, the proposed dynamic key management framework was able to adapt well to changing network conditions. It brought down the broadcast overhead and resulted in efficient message delivery.

The proposed solution performed comparably to traditional frameworks that started to degrade performance in larger networks, but with minimal latency increase. Smart contracts based on blockchain made sure that the important exchanges were safe and efficient even when traffic is higher [6]. Results of the system's scalability owing to low overhead implied its feasibility to use this approach in various IoT environments, such as smart home and as industrial control systems.

5. Comparative Analysis with Existing Solutions

In comparison to current systems, the proposed system excels in integrating security with performance and low resource usage. For example, conventional static encryption protocols face challenges in adapting to dynamic attack pattern, which in turn increases the vulnerability in the changing IoT environments [5]. The proposed solution integrated the adaptive key management techniques in order to enhance anomaly detection by leveraging the AI and the capabilities of the operational concept. Further, blockchain technology was used to improve the reliability of key exchange transactions and solve the shortcomings of the traditional centralized key management system [6].

Moreover, in the low power IoT environments, cryptographic protocols usually adding high computational overhead, the system's lightweight encryption modules showed high performance. The PRESENT and SIMON ciphers [7], [8] were combined to achieve optimal security with minimal impact on the system performance.

6. Real-World Implications and Practical Applications

The proposed key distribution mechanism with AI has a large amount of potential for the real world deployment in smart infrastructure, healthcare, and industrial IoT applications. With low latency performance, it is reliable in time sensitive environments, and its energy efficient design allows for an extension to battery powered device operational lifetime. The system incorporating blockchain technology solves the trust problem of centralized security models and is appropriate for large scale IoT ecosystem [6].

In addition, the adaptive security model has the capability to respond to the changing threats in a dynamic fashion and thus, the system can be considered as a robust solution to tackle the advanced network attacks. This is particularly useful in the critical infrastructure deployment where a security breach can lead to very bad consequence.

The proposed AI powered key distribution mechanism in the end achieves lightweight encryption in addition to leveraging machine learning based threat detection and blockchain enabled trust management for a larger scale applied to the IoT security and thus results in notable advancements in the IoT security. And the real world adoption potential of such a framework is ultimately validated by its experimental results, which offer better performance, scalability and resilience than existing key distribution frameworks.

V. CONCLUSION AND FUTURE ENHANCEMENT

The paradigm that is proposed by this research, is to use Machine Learning based threat detection, integrate lightweight cryptography, and the blockchain enabled trust management, to provide a AI powered key distribution mechanism for IoT. The system was designed to solve the critical challenges in secure key exchange for resource constrained IoT devices. It is shown that the proposed framework can improve the security performance by a large margin, reduce latency, and gain benefits in terms of energy efficiency over traditional key management approaches.

Lightweight encryption protocols PRESENT and SIMON were adopted in order to minimize the computational overhead and yet be sufficiently robust against cryptanalytic attacks [7], [8]. In particular, these lightweight ciphers made these devices particularly secure as they are resource constrained devices with limited processing power. Further improving the system's capacity to alleviate new security threats was the system’s utilization of machine learning techniques for the purpose of anomaly detection. In addition, the adaptive zero security identified and responded zero-day attacks following a dynamic augmentation of security protocols in real time with the threat detection accuracy of 89% [6]. It greatly outperforms existing static security framework which are often blinded by the changing attack patterns.

The use of blockchain technology greatly enhanced the security of key exchange transactions. To achieve tamper-proofs and decentralised key distribution, a system was built by taking advantage of Hyperledger Fabric’s smart contract framework. This helped to guarantee the integrity and authenticity of keys between distributed IoT nodes and prevented risks such as replay attacks and man in the middle threats [6]. However, even on real time communication environment, the system proved to be highly resilient by improving its ability to dynamically revoke the compromised session keys.

In the performance aspect, the system proposed in this paper reduces the key distribution latency by 32% compared with classic frameworks, thus being more responsive for time critical IoT applications. The clusteringbased communication strategy of the system led to the improvement of latency, as it reduced redundant data exchanges and minimised network congestion [3]. Additionally, the system was also reduced by 27% in terms of energy consumption, which makes the system sustainable to operate in battery powered IoT environments. Optimized encryption routines and strategically clustered methods that eliminated the undesirable message exchanges were used to reduce unnecessary message

exchanges, conserved device power [4]. Latency, energy efficiency, and security improvements, the benefits of using the system are presented and analyzed.

Despite strengths of the system proposed, there are several limitations that need to be further investigated. Second, the PRESENT and SIMON ciphers may be good choices for lightweight encryption, but their security is subject to the progress in quantum computing. Future research in this area, therefore, would examine the aspects of integrating in postquantum cryptographic algorithms that are more resilient to quantum attack variants. Moreover, the computational overhead introduced by the blockchain framework is negligible in this implementation; however, this overhead can be large in large scale IoT networks consisting of thousands of nodes. In future, the efforts should be directed towards the enhancement of blockchain performance in terms of compression of transaction processing time and its ability to support consensus mechanism in real time which are essential in large IoT Ecosystems in order to granting rightful compensation and trust in service provision [6].

An additional limitation is that adaptive security relies on machine learning models. However, the accuracy rates achieved by the trained models could reduce in rapidly changing threat environment or networks lacking with data availability. As a future work, future investigation should be made on building lightweight AI models which can learn continually using the real time network traffic data. Further, this system can be made adaptive to the changes by empowering IoT nodes to learn collaboratively by implementing federated learning approaches in which few nodes can train models without centralizing data [2].

The proposed system was also evaluated for its scalability using 50 nodes in a controlled experimental setup. Results also showed that the sensing service was able to sustain stable performance under increased network loads however, further testing in IoT environments of larger scale and dynamics will be needed to determine scalability in the real world. Albeit, additional future work can be conducted on the hierarchical clustering methods and multi tiered security models in an attempt to enhance the capability of the framework to address large scale deployment efficiently [3].

The practical implications of this research are in terms of several IoT application scenarios such as smart homes, healthcare systems, and industrial automation. As an example, in the context of healthcare settings the real time detection of abnormal network behaviour on the system can enhance the protection of sensitive patient data from cyber attacks. The key distribution framework can ensure the secure communication of twisted between thousands of interconnected sensors in a smart city deployment and minimize power consumption.

Blockchain technology also helps to further enhance trust in secure transactions and this system is more useful in the securing financial and commercial IoT networks.

Therefore, proposed AI based key distribution mechanism is advancement in IoT security utilizing lightweight cryptography, adaptive machine learning model, and blockchain trust management to guarantee trust. The system effectively solves problems in key distribution frameworks and improves security, performance, and energy efficiency. However, staying resilient to quantum threats and scalability remain unsolved challenges, although the proposed solution provides a sound groundwork that can further be improved. Future iterations of this framework can improve with the incorporation of emerging cryptographic standards, enhancement to the machine learning adaptability, and refinement of the blockchain scalability, thus improving the IoT security and safe and efficient communication in large – scale networks.

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