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Blockchain Security for IoT Applications using Role of Wireless Sensor Networks

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Abstract

The rise of the Internet of Things (IoT) has brought untold numbers of devices into our lives, using them all to build a commonplace of smart and data driven spaces. Wireless Sensor Networks (WSNs), at the central core of this technological revolution, are the foundation of IoT applications by collecting and transmitting vital data. But as the networks get more complex and more important, so do the security challenges it faces. Here comes blockchain technology, a novel method to make WSNs in the IoT more secure, trustworthy and accountable. With WSNs becoming more and more a part of our critical appointments such as healthcare, smart cities and industrial automation now more than ever we cannot risk their security and availability. It is well known, however, that traditional security mechanisms are typically insufficient when applied to these distributed networks as they are highly resource constrained sensor nodes. Blockchain technology enters the arena as a watershed solution functionally decentralizing and tamper-resistant data management and network security. In this that explores from an aspect of WSNs and IoT applications, blockchain technology and its intricate relationship with WSNs in the age of IoT applications is explored comprehensively. In this paper, we explore how blockchain's built in features could be used to overcome the security vulnerabilities of WSNs, improve data integrity and establish robust accountability mechanism. This article strives to be a one-stop read to understand from the fundamentals of blockchain integration to advanced implementation strategies how this ground breaking technology is changing the world of IoT security.

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Introduction

Through this topic, we will come to the know of the potential benefits, challenges & the upcoming trend of blockchain enabled WSN. Whether you're an experienced IoT individual, a blockchain devotee, or simply taking a look at the future of secure, connected systems, this investigation will provide you with indispensable perceptions in one of the most daunting mixes of cutting edge accomplices we've at any point had.[1-3]

Wireless Sensor Networks in IoT

Wireless Sensor Networks (WSN) are fundamental components of the plethora of Internet of Things (IoT) applications that currently exist or will manifest in the near future, gathering data from the physical world and transferring it wirelessly to digital platforms. Spatially distributed autonomous sensors monitor a variety of environmental or physical conditions, including temperature, sound, pressure, or motion, in these networks. These sensors collect the data -- which is then transmitted through the network to central locations for analysis, and action. In the field of IoT, WSNs screen out the gap between the physical and the virtual world. It enables real time monitoring and data collection of a myriad of fields; environmental monitoring, healthcare, industrial automation, smart

homes and urban planning. WSNs are versatile and scalable, and are absolutely indispensable for building intelligent, responsive systems capable of adapting to change, whether in the context of user need or changing environmental conditions.

However, sensors nodes in WSN are often resource constrained and the distributed nature of WSNs themselves poses unique challenges regarding security and data integrity. With these networks becoming more prevalent and utilized while tasked with more and more sensitive information, security must be top priority. The limited computational capabilities and distributed architecture of WSNs makes traditional security measures fail in meeting the specific needs of these sensor networks. Additionally, as the scale of the IoT deployments is on the rise, the security risks for WSN are also amplified. With billions of connected devices generating and transmitting data, the opportunity for malevolent actors to increase their potential attack surface exponentially. In such issues such as data tampering, unauthorized access, and node compromise conventional security approaches will no longer be feasible and the problems become more prevalent and harder to tackle. But blockchain technology comes in and addresses this problem by a different, novel way of securing WSNs in IoT environments. The decentralized, tamper resistant characteristic of blockchain allows many of the security and integrity concerns associated with traditional WSN implementations to be addressed. By integrating blockchain with WSNs, we have promise to free security in IoT ecosystem to the level of more robust, more trustworthy and more efficient sensor networks.[4-7]

Fundamentals of Blockchain Technology

Widely conceived as underlying mechanism for digital currencies such as Bitcoin, blockchain technology has been developed into a versatile, powerful tool with uses far beyond that. Blockchain is essentially a distributed ledger technology that lets you record transactions or data in a secure, transparent and unchangeable way in a collaborative network of computers. In general, a blockchain is simply a chain of blocks, where a block is a collection or set of transactions (data) These blocks are put together on a linked basis using cryptographic hashes to make one unbroken chain of information. This structure is, once the data was recorded into a block and added to the chain, virtually impossible to alter or tamper with without detection.

Since its entire infrastructure is decentralized, blockchain technology is one of its most distinctive traits. While there are other areas where we have come to expect data to be centralized, like local files, or a server with a database, blockchain goes against a very traditional model of data, where a single authority largely controls it. It is also decentralized such that it becomes immune to attacks or failures on the part of a single point of failure. Consensus mechanism is crucial in another part of where block chain is concerned, which is that all the nodes in the network are required to have the same idea about the state of ledger. Consensus algorithms like Proof of Work (PoW), Proof of Stake (PoS) and Byzantine Fault Tolerance (BFT) are used to make the nodes agree to this among themselves. And not only do these mechanisms ensure that the integrity of the blockchain is preserved, but also keep the system from being manipulated by malicious actors (Figure 1).

Many blockchain platforms will have powerful features such as smart contracts. They are just self-executing contracts where the terms of the agreement are written directly into code. The smart contracts provide us with a way to automate complex processes, enforce rules, and make trustless interactions between parties possible without any of the intermediaries. Because of its immutability and transparency, blockchain technology is an ideal technology for applications with very high security and accountability requirements. As soon as data is put in the blockchain, or stored as a record in the blockchain, it can't be tampered with, changed, deleted, etc., without leaving some kind of a trace. In cases where data integrity and auditability are critical elements in financial transactions, supply chain management and increasingly in securing Wireless Sensor Networks for IoT applications, this feature is especially beneficial. Heading towards the block of blockchain applied in securing WSNs, it is essential to find out that these essential features of blockchain technology can be utilized to tackle the particular security challenge in IoT environment.

Wireless Sensor Networks: Security Challenges.

As we stated before, a myriad of security challenges exist in Wireless Sensor Networks (WSNs) which are due to their distributed nature, constrained resources and often hostile environments in which they operate. False data may be injected by malicious actors or data

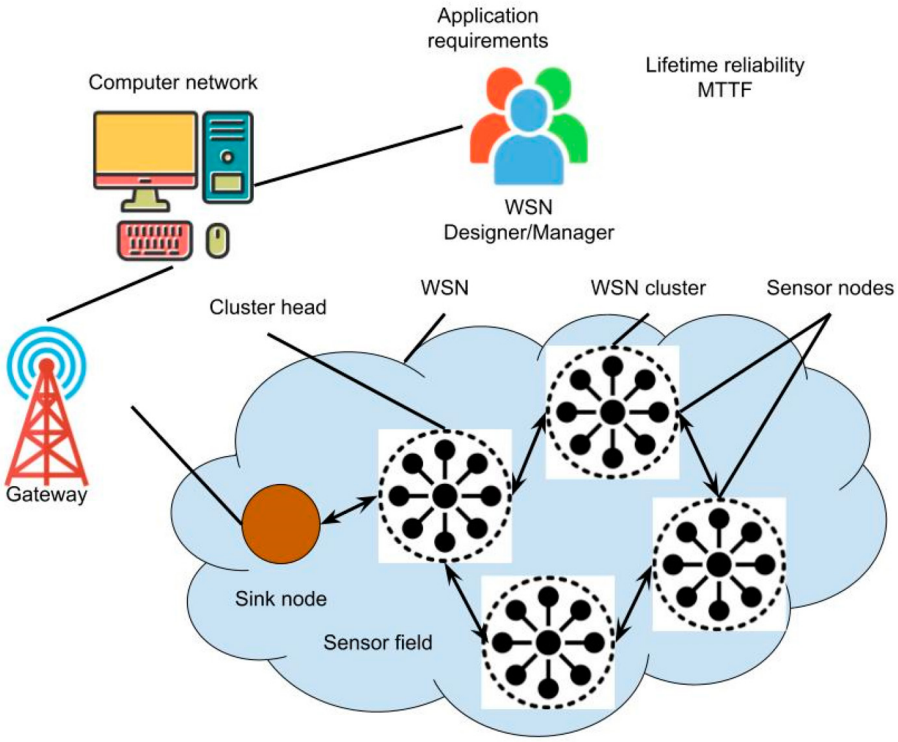

Fig. 1: Wireless Sensor Networks in IoT

may be modified to put information that is incorrect to lead to bad decisions or even bad decisions from compromised information.

There's another set of challenges in authentication and access control. Identity verification and access control of nodes and sensitive data, or network resources and their configuration, may are not simple for large scale WSNs. Usually the authentication methods used are not applicable for resource constrained sensor nodes, then making network prone to un authorised access and data breaches.

Another common concern is privacy, especially in cases where sensitive data is interacted with; healthcare are typical examples. Data confidentiality is vital when travelling through the network and that only authorized people can handle and understand the data.

WSNs possess a distributed nature, which adds up to be their characteristic vulnerability to many kinds of attacks. These include:

1. **Node capture attacks:** Where an attacker physically makes contact to a sensor node and gains access to its cryptographic keys, or other sensitive information.
2. **Sybil attacks:** It is scenario of a malicious node takes advantage of his power to create other node to allow him to gain disproportionate influence over the network.
3. **Denial of Service (DoS) attacks:** To saturate the network (or specific nodes) with traffic in order to disrupt normal operation.
4. **Man-in-the-middle attacks:** These happen when nodes communicate, but an attacker intercepts and potentially alters the communication.
5. **Replay attacks:** Reversing transmitted data packets so that they appear to be malicious.

Sensor nodes constrain security implementations with energy. Many traditional security protocols are too resource demanding for the computational and energy capabilities of the typical sensor nodes. Security and network longevity are often constrained by this;

It is also a difficult issue since the scaling needs to extend to people, automation, information, storage, and the infrastructure support necessary. However, with the advent of larger and more complex WSNs, the task presents itself as being increasingly difficult to manage security across this large number of nodes. For a large, distributed network, this is a difficult task of maintaining consistent security policies and rapid response to threats. Secondly, a lot of modern WSN deployments have dynamic nature and nodes can join and leave frequently which complicates the question

of how to maintain a consistent security posture. Security frameworks that can adapt to changing network topologies and node populations are required to adapt security measures. In order to address the multifaceted security challenges of WSNs, we harness this natural property to develop innovative approaches to provide comprehensive protection while keeping the unique characteristics of WSNs in mind. But blockchain technology gains a place as a potential solution to address many of these vulnerabilities with fresh and powerful features.[8-11]

Solution of WSN Security Using Blockchain

The security challenges towards WSNs in IoT applications are addressed by the use of the Blockchain technology. Being a technology based on characteristics of decentralization, immutability and transparency, blockchain provides solutions to many of the security issues that plague traditional WSN technologies.

Table 1: Blockchain Security Mechanisms for IoT

Mechanism	Purpose
Data Integrity	Data integrity ensures that the data transmitted across IoT networks is not tampered with, protecting its authenticity and accuracy using blockchain technology.
Authentication Protocols	Authentication protocols verify the identity of IoT devices, preventing unauthorized access and ensuring secure communication between devices and the blockchain.
Access Control	Access control mechanisms ensure that only authorized users and devices can access certain parts of the IoT network, providing secure and restricted access.
Consensus Algorithms	Consensus algorithms validate transactions within the blockchain, ensuring that all IoT nodes agree on the state of the system and preventing fraudulent ac tions.
Cryptographic Hashing	Cryptographic hashing secures data by converting it into a unique code, which is used for verifying data integrity and ensuring its secure transmission across IoT networks.
Smart Contracts	Smart contracts are self-executing contracts with the terms of agreement directly written into code, enabling automatic and secure transactions between IoT devices.

Providing integrity for data served as one of the primary ways blockchain enforces security in WSN. In this paper, we apply the blockchain not only to blockchain-enabled WSNs, but also to the category of WSNs that already include a built-in database. In other words, this makes the task of malicious actors extremely difficult if they are not to be detected whilst they alter or inject false data. Any change done to the data would be seen by the next block in the chain of cryptographic hashes that went into creating the block. The use of blockchain technology can greatly help in authentication and access control in WSNs. Blockchain and bitcoin to some extent are not permissioned systems: everyone can join and profit without prior permission from the system. The advent of smart contracts deployed on the blockchain enables us to define and subsequently enforce access rules; for example, only authorized nodes or users can interact with specific parts of the network, or only certain types of data, ensuring a certain level of control instead of autonomy. In this decentralized way of access control, there is no single point to fail and use offers a more solid and flexible authentication mechanism.

Cryptography features of blockchain can aid the WSNs to address the privacy concerns. Unlike blockchain transactions, which are almost by definition public, there are often ways to obscure a transaction's sensitive information while still allowing for it to be scrutinized from an audit or integrity standpoint.

Many types of attacks of WSNs can be mitigated by blockchain's consensus mechanisms.• But Sybil attacks become much harder to run in a blockchain network; if there are multiple identities to create then to participate to the consensus process would require a great deal of computing power.• Decentralized blockchain network would be less susceptible to Denial of Service (DoS) attacks as there is no single point of failure to attack.• As we use blockchains public key cryptography for the communication between nodes, man in the middle attacks can be prevented.he agreement directly written into code. Smart contracts can automate complex processes, enforce rules, and facilitate trustless interactions between parties without the need for intermediaries. The immutability

and transparency offered by blockchain technology make it particularly attractive for applications requiring high levels of security and accountability. Once data is recorded on the blockchain, it becomes virtually impossible to alter or delete without leaving a trace.[12-15]

Blockchain as a Solution for WSN Security

- Man-in-the-middle attacks can be prevented by using blockchain's public-key cryptography for secure communication between nodes.

By implementing tailored lightweight blockchain protocols designed for IoT and WSN environments, we address the energy constraints of sensor nodes. By making these protocols, individual sensor nodes can enjoy the security benefits of blockchain at a much reduced cost of computing and energy cost. Blockchain technology provides scalability challenges in WSNs to be handled efficiently. But this doesn't mean that just any node can be added to the blockchain network as it grows, they would inherit the security properties and access rules defined by smart contracts. This enables WSNs to more easily and securely scale. Furthermore, there is no better mechanism than blockchain's capacity to develop a shared, distributed ledger of all network activities with absolutely no levels of accountability or auditability like none before it. In scenarios where you'll need to track the provenance of data or actions of nodes at scale as in healthcare or industrial IoT applications, this feature is really valuable.

Solution of these security challenges enable blockchain technology to provide more secure, reliable, and trustworthy WSNs in IoT ecosystems. Along the lines of the integration of blockchain with WSNs, we will further investigate on specific implementations and on the possible influence this can have in other IoT application areas (Figure 2).[16-19]

Implementing Blockchain in WSNs: Strategies and Approaches

Explicitly, blockchain technology implementation in Wireless Sensor Networks is an intricate task that requires careful consideration of the special characteristics and constraints of these networks. A few ideas have been produced to efficiently combine

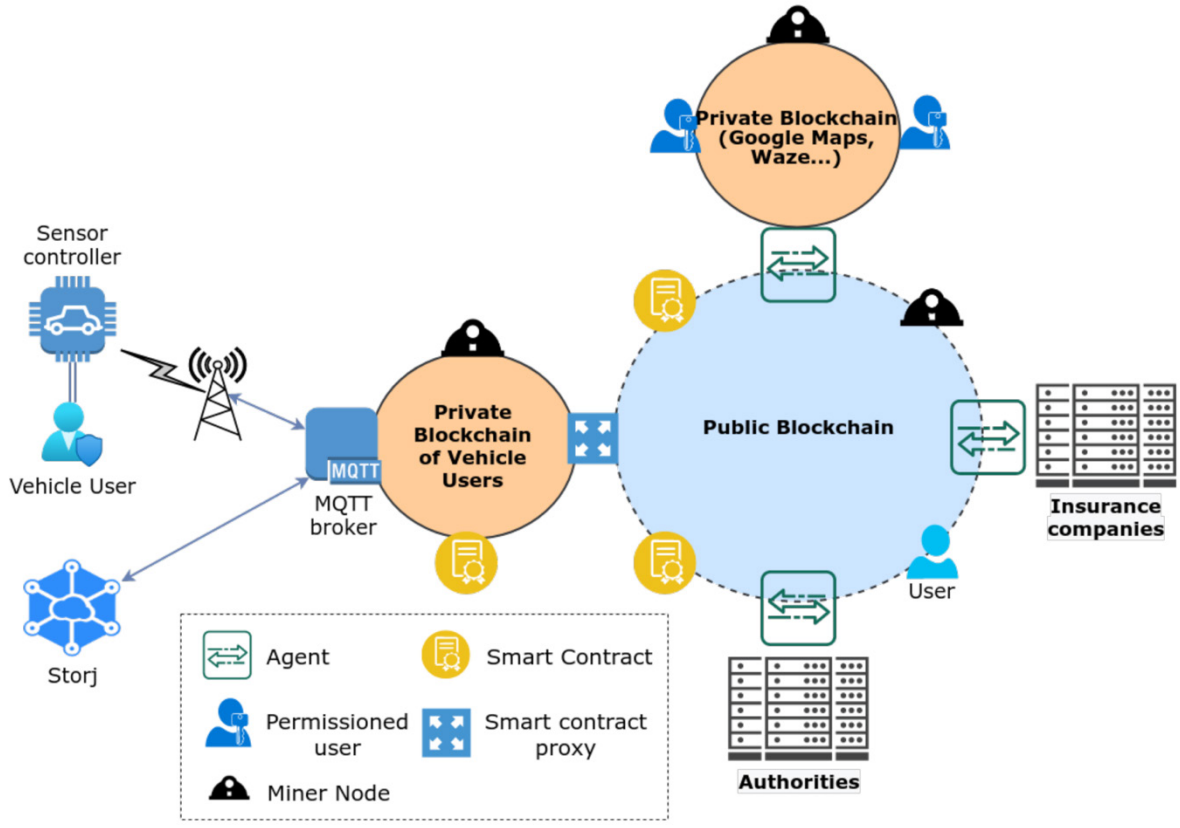

Fig. 2: Blockchain as a Solution for WSN Security

blockchain with WSNs tackling different facets of security and provision in order. For example, a typical approach is to make use of resource constrained applications run on topology massively deployed lightweight blockchain protocol. The goal of these protocols is to reap the security benefits of blockchain while keeping computational and energy costs low. For instance, simplified consensus algorithms work that are less power and resource intensive than typical Proof of Work (PoW) will make them more suitable for sensor node having limited processing capacity and energy reservoir.

Table 2. Role of Wireless Sensor Networks in IoT Blockchain Security

Role	Contribution
Data Collection	Wireless sensor networks collect real-time data from IoT devices, providing a secure and reliable source of information for blockchain applications.
Event Detection	Event detection identifies anomalies or critical events in IoT systems, triggering automated responses and feeding accurate data into the blockchain for validation.
Secure Communication	Secure communication between IoT devices and blockchain nodes ensures encrypted data exchange, maintaining privacy and security throughout the system.
Real-Time Monitoring	Real-time monitoring ensures that sensor data is continuously monitored, providing up-to-date information to validate transactions and improve system reliability.
Distributed Ledger	A distributed ledger maintained by wireless sensor networks ensures decentralized, transparent, and tamper-proof storage of IoT transaction data on the blockchain.
Fault Tolerance	Fault tolerance in sensor networks ensures that even if some nodes fail, the system continues to function securely, providing uninterrupted data for blockchain verification.

The other method involves constructing hierarchical blockchain structures (structures) within the WSN. In this approach, sensor nodes are organized into cluster and a cluster head is assigned from each cluster. Cluster heads themselves get into the blockchain network and normal sensor nodes inside each cluster communicate to their respective cluster head. Distribution of computational load of blockchain operations is done in an efficient manner across network via this hierarchical structure.

Edge computing implementations offload blockchain operations alternatively from resource constrained sensor nodes. However, in this model, the more intensive blockchain tasks of block creation and verification are deployed by edge devices or gateways with more computational power and sensor nodes do the tasks of data collection and basic verification. Another approach that can be very beneficial to deployment in WSN environments is the use of permissioned blockchains. Permissioned blockchains are different from public blockchains that allow anyone to participate, permissioned blockchains allow to participate only to authorized nodes. This will significantly reduce the overhead of computing and increase the network efficiency, than it looks appropriate for WSNs with limited resources.[20]

Many blockchain-WSN applications rely on smart contracts. By defining and enforcing security policies and automatically enforcing various network operations, these can be used as self executing contracts to manage access control. For instance, smart contracts can be written that will perform some action or send an alert whenever there is specific sensor reading. However, certain new approaches that incorporate blockchain with other rising technologies are conducting WSN security. For an example, blockchain integration with machine learning algorithms can result in smart adapter security systems which can more effectively detect and respond to newly identified threats. In addition, data storage strategies of the data storage strategies of implementing blockchain WSNs also play important roles. Some implementations, constrained by the by limited storage capacity of sensor nodes, use off chain storage solutions where the blockchain only stores the hash or metadata of the full data. Though it retains the integrity and verifiability advantages of blockchain, it also takes the storage load of sensor nodes down to a reasonable number.

The interoperability between blockhain and WSN is also important. However, since IoT ecosystems typically involve many kinds of networks and devices, it is important that blockchain enabled WSN's are able to work with other systems seamlessly. Others look at creating cross chain data exchange and verification approaches to work between different blockchain

networks. Finally, energy efficient consensus mechanisms are being developed to enable blockchain WSNs integration. The goal is to reach network consensus at minimum energy consumption in order to extend the operational lifespan of battery powered sensor nodes. The integration of blockchain WSN is an emerging field and there will be new strategies and approaches developed, as the field of blockchain WSN integration continues to develop, further improving the security, efficiency, and functionality of these integrated systems. Implementing blockchain on WSNs for IoT applications requires careful balancing between blockchain security benefits and resource constraints and usage requirements of WSNs, towards achieving the goal of blockchain implementation success.

Blockchain based enhancing Data Integrity and Accountability in WSNs

The biggest contribution of the blockchain technology to Wireless Sensor Networks (WSNs) is data integrity and accountability improvement. Reliability and trustworthiness of the data collected and transmitted by WSNs in different IoT applications are dependent on the following two aspects.

In WSN, blockchain's immutable ledger offers a tamper evident record of all data transaction. Any data recorded on the blockchain is almost impossible to change or eliminate without detection.

1. **Data Collection:** As sensor nodes, they gather data of their environment.
2. **Data Hashing:** The data is hashed to create a unique digital finger print.
3. **Block Creation:** A new block is created that includes the data hash, and other relevant information.
4. **Consensus:** The new block is then made valid to the network, and the network agrees.
5. **Block Addition:** A block is added to the blockchain and validated.

Conclusion

In many of the IoT applications that deal with sensitive data or require critical operations, this level of accountability is a must. Accountability within blockchain enabled WSNs is ensured by smart contracts. These self executing contracts can be used to program these to automatically initiate actions or alerts at specific conditions or events. For instance, there could be a smart contract to notify it of any odd sensor signals or to execute some predefined response protocol if it detects anomaly. Furthermore, by combining data integrity and accountability of blockchain, we improve the overall trust in WSN system. By verifying the data using a decentralized network stakeholders can be more confident that the data they receive has been verified and cannot be easily manipulated. Sensors this trust is particularly important for such application, where sensor data is used to take critical decisions, or to trigger automated response to them. In addition, the generation of an immutable audit trail of all the network activities presented by blockchain is extremely useful to system administrators and auditors. In regulated industries or for forensic analysis in case of security incidents, this feature is especially useful as it is useful for compliance purposes. Blockchain technology tries to solve some of the most important security issues in WSNs by improving data integrity and accountability. It serves as a solid foundation for building more secure, more reliable, and more trust

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