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IoT Architectures based on Blockchain Technologies

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***Abstract*—** We are witnessing an exponential growth of the Internet of Things (IoT) market. Across the globe, wherever there is internet connectivity, each individual owns multiple devices which are connected to the internet. Further, there are "things" which are directly connected to each other through the internet and act independent of human intervention by participating in automated business processes to provide business value. A wide range of IoT applications have been developed and deployed in the recent past. However, the IoT technologies have some inherent drawbacks and challenges, for e.g. security and scalability issues.

On the other hand the use of blockchain technologies is also experiencing an exponential growth, even beyond the financial applications. As both IoT and blockchain technologies are finding widespread acceptance, researchers and practitioners have experimented with the adoption of blockchain technologies for IoT based applications with a view to build robust and state of the art systems. Such initiatives have been quite successful.

This paper reviews the current research status of IoT and blockchain technologies and discusses how the blockchain technologies are leveraged to address some of the challenges faced during the development of IoT based applications. It identifies research trends and future scope to build IoT architectures based on blockchain technologies.

***Keywords*—** IOT, Blockchain, Security, Distributed Ledger, Sensors, Actuators, SOA, Reference Architecture, Ethereum, Raspberry Pi, Scalability, Digital Transformation,

I. INTRODUCTION

There is a wave of digital transformation cutting across industries.

IoT tops the list of top 10 trends for digital transformation in 2018. The analytics revolution, edge computing and 5G cell processing are all driven by the IoT at their core. Following the IoT, anlaytics, edge computing and 5G technologies is the blockchain technology in the list of top 10 trends for digital transformation in 2018. [1]

Experience has shown that IoT based projects do have certain limitations and implementation challenges. A recent trend is to leverage blockchain technologies for addressing some of these limitations and challenges.

This paper presents an overview of the IoT and blockchain technologies. It then reviews some of the blockchain based IoT applications and provides direction for future work. Research needs to be carried out to develop architectures and frameworks for blockchain based IoT applications in order to help architects, designers, developers and project managers involved in such projects.

The rest of this paper is organized as follows. Section II contains the overview and applications of Internet of Things. Section III provides the overview and applications of blockchain. Section IV discusses the interplay of IoT and blockchain. Section V contains the conclusion and future scope. It is followed by references.

II. INTERNET OF THINGS

The term Internet of Things generally refers to scenarios where network connectivity and computing capability extends to objects, sensors and everyday items not normally considered computers, allowing these devices to generate, exchange and consume data with minimal human intervention. There is, however, no single, universal definition. [2]

IoT integrates various devices equipped with sensing, identification, processing, communication, and networking capabilities. Sensors and actuators are getting increasingly powerful, less expensive and smaller, which makes their use ubiquitous. [3]

IoT and Industrial IoT (IIoT) applications cut across domains like Agriculture, Automotive, Consumer Electronics, Healthcare, Industrial Automation, Logistics, Smart City, Smart Energy, Smart Retail, Sport & Fitness and Telecom. [4]

Industries have a strong interest in deploying IoT devices to develop industrial applications such as automated monitoring, control, management and maintenance. IoT is an ideal emerging technology to influence this domain by providing new evolving data and the required computational resources for creating revolutionary apps. Due to the rapid advances in technology and industrial infrastructure, IoT is expected to be widely applied to industries. For example, the food industry is integrating WSN and RFID to build automated systems for tracking, monitoring, and tracing food quality along the food chain in order to food quality. [3]

The Industrial Internet Consortium has published a very useful document containing the Reference Architecture for Industrial IoT systems. [5]

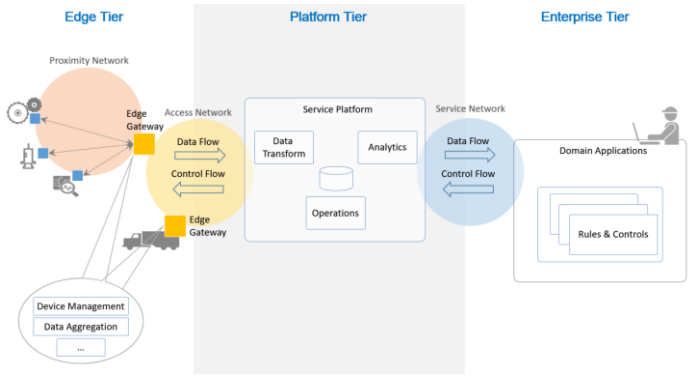

Figure 1: Three-Tier IIoT System Architecture [5]

Established approaches for implementation of the "platform tier" deal with on-premise or cloud platforms. Some popular commercial IoT platforms are Amazon Web Services IoT Platform, Microsoft Azure IoT Hub, IBM Watson IoT Platform and Google Cloud Platform. Some popular open source IoT platforms are Eclipse Kura, Node-RED and Kaa Project.

III. BLOCKCHAIN

The blockchain is a term that has come to mean many things to many people. For developers, it is a set of protocols and encryption technologies for securely storing data on a distributed network. For business and finance, it is a distributed ledger and the technology underlying the explosion of new digital currencies. For technologists, it is the driving force behind the next generation of the internet. For others, it is a tool for radically reshaping society and economy taking us into a more decentralized world. [6]

The blockchain was initially created as a distributed and immutable ledger of transactions for cryptocurrency systems. Thanks to the invention of smart contracts (executable codes that reside in the blockchain), the blockchain has now evolved into a promising platform for developing distributed and trustworthy applications, and has attracted considerable attentions from researchers in the IoT. [7]

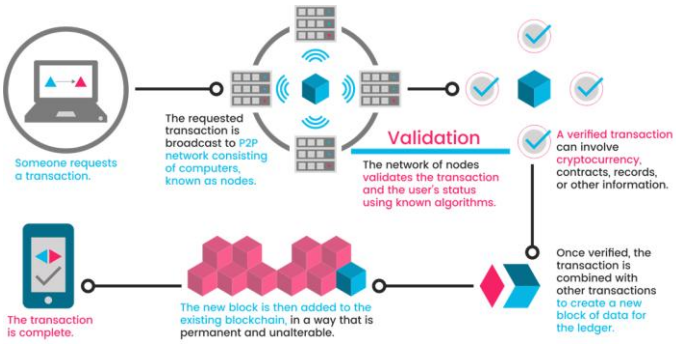

Figure 2: How Blockchain works [8]

A smart contract is executable code that runs on the blockchain to facilitate, execute and enforce the terms of an agreement between untrusted parties. It helps act like an expert evidence of as a system that releases digital assets to all or some of the once the pre-defined rules have been met.

Compared to traditional contracts, smart contracts do not rely on a trusted third party to operate, resulting in low transaction costs. There are different blockchain platforms that can be used to develop smart contracts, but Ethereum is the most common one. [9]

Some popular commercial blockchain platforms are IBM Blockchain, SAP Leonardo and Microsoft Blockchain-as-a-Service (BaaS). Some popular open source blockchain platforms are Ethereum, Hyperledger and Corda.

IV. IOT AND BLOCKCHAIN

Internets of things (IoT) solutions are being successfully adopted in many different industries, such as healthcare, warehousing, transportation, and logistics. However, IoT applications do face certain challenges. For instance, current centralized, cloud-based IoT solutions may not scale and meet the security challenges faced by large-scale enterprises. The use of blockchain as a distributed ledger of transactions and peer-to-peer communication among participating nodes can solve such problems. Table 1 presents the potential

blockchain solutions to address some implementation challenges.

Table1. How Blockchain can address IoT challenges. [10]

.Challenge	*Explanation*	*Potential blockchain solution*
Costs and capacity constraints	It is a challenge to handle exponential growth in IoT devices: by 2020, a network capacity at least 1,000 times the level of 2016 will be needed.	No need for a centralized entity: devices can communicate securely, exchange value with each other, and execute actions automatically through smart contracts.
Deficient architecture	Each block of IoT architecture acts as a bottleneck or point of failure and disrupts the entire network; vulnerability to distributed denial-of-service attacks, hacking, data theft, and remote hijacking also exists.	Secure messaging between devices: the validity of a device's identity is verified, and transactions are signed and verified cryptographically to ensure that only a message's originator could have sent it.
Cloud server downtime and unavailability of services	Cloud servers are sometimes down due to cyberattacks, software bugs, power, cooling, or other problems.	No single point of failure: records are on many computers and devices that hold identical information.
Susceptibility to manipulation	Information is likely to be manipulated and put to inappropriate uses.	Decentralized access and immutability: malicious actions can be detected and prevented. Devices are interlocked: if one device's blockchain updates are breached, the system rejects it.

Since the beginning of 2018, a few reports and articles predicting the next boom in the tech world mentioned that the Blockchain Internet of Things might be the next key development. Moreover, by 2019, 20% of all IoT deployments might have basic levels of blockchain services enabled.

Blockchain's incorporation into IoT is being supported through a wide variety of measures intended to strengthen security. Several companies are leading initiatives to integrate blockchain into their production and supply chains. For instance, IBM is using its large cloud infrastructure to provide blockchain services for tracking high-value items as they move across supply chains.[10]

Measures are also taken at interorganizational levels. A group of technology and financial companies have announced that they have formed a group to set a new standard for securing IoT applications using blockchain. Companies joining the group include Cisco, Bosch, Bank of New York Mellon, Foxconn Technology, Gemalto, and blockchain startups Consensus Systems, BitSE, and Chronicled.This group hopes to establish a blockchain protocol to build IoT devices, applications, and networks. [10]

Startups such as Provenance use blockchain to promote trust in the supply chain by providing transparency and visibility when the product moves from the source to the customer. [11] Others are creating new business models that eliminate the need for centralized cloud servers. For example, Filament, a blockchain-based solutions provider for IoT, has launched wireless sensors, called Taps, that allow communication with computers, phones, or tablets within 10 miles. [10]

A startup called Filament is using IoT hardware and software for several industrial applications, which include — but are not limited to — manufacturing and agriculture.

The company's new Blocklet application software and Blocklet Chip hardware solutions let all the connected devices and machines exchange a value against blockchain. This helps maximize the potential of all the devices that are connected. The transactions between machines happen in real-time with no access to connectivity or cloud. Moreover, device identification and communication is secured with a Bitcoin blockchain. It performs the role of holding the unique identity of the participating nodes in the network.

Another instance where IoT meets blockchain is Telstra, the Australian telecommunication giant, wherein it is leveraging blockchain technology to secure its smart home ecosystem.

IoT and blockchain are also going to change monetization by letting owners of devices and sensors share the generated IoT data in exchange for micropayments done in real-time. A case in point is that of Tilepay.

This enables users to register their devices and sell the data in real-time. As a result, they will earn digital currency.

"The blockchain can support 2^106 addresses. To put that into perspective, it is estimated that there are 2^63 grains of sand on earth. So, 2^106 would be the equivalent of a thousand planets' worth of grains of sand. And each and every blockchain addressed is directly addressable (one can send a message directly to that address) allowing the registration and command and control of an immeasurable number of devices. "Gartner research predicts there will be 20.8 billion IoT devices by 2020. This is approximately 2^34, which is readily handled by blockchain technology." [12]

Due to the growing popularity of the Blockchain based IoT applications, quite a few posts and tutorials have been published. [13], [14]

A PoC, based on [14] has been implemented using a laptop and a Raspberry Pi. The series of tutorials describes how to set up a private Ethereum blockchain that will be composed of a computer (miner) and a Raspberry PI 3 device (node).

The objective is to build a development environment to learn about blockchain principles, to develop and test one's own smart contracts before releasing them to the live chain (mainnet). The tutorial involved integrating a RPi with a Smart Contract deployed on a private chain. The Smart Contract was used to check if a user has enough tokens to use a service. The RPi has been used to visualize the status of the contract.

Figure 3.Raspberry Pi connected to MacBook Pro

Figure 4. Mist Browser for Ethereum on Mac

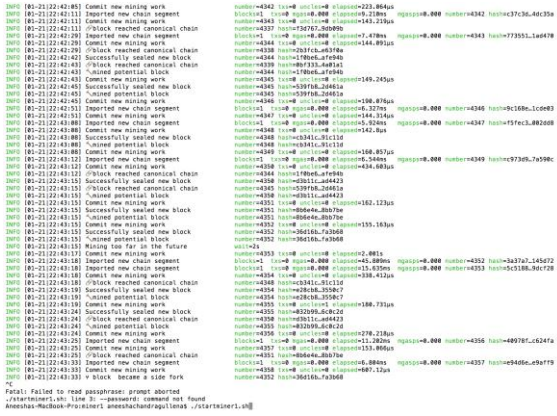

Figure 5. Instantiation of a Mining Server

By modifying the smart contract code the PoC could be extended to address functional requirements like taking an action based on conditions like exceeding a specified temperature or making micropayments based on specified criteria.

V. CONCLUSION AND FUTURE SCOPE

From what has been presented in this paper it is evident that blockchain technologies would have a great amount of influence on the discipline of IoT going forward. Based on the implementations discussed in the earlier section, it can be surmised that already there are some inherent architectures for blockchain based IoT applications. This implies that it is necessary to carry out further research to identify, refine and document appropriate frameworks, reference architectures and methodologies.

In [15], it is suggested that the blockchain for IoT adopt a layered architecture which supports thin clients to allow IoT devices with limited resources to store only a portion of the blockchain.

The decentralized and heterogeneous nature of IoT requires that architecture based on IoT provides efficient event-driven

capability. Thus, SOA is considered a good approach to achieve interoperability between heterogeneous devices in a multitude ways [16]. This author was instrumental in the development of SOA based architectures and frameworks [16], [17]. The future scope of work includes development of such reference architectures and frameworks for IoT and blockchain based applications.

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