Towards Cloud Computing and Blockchain Integrated Applications

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***Abstract*—Cloud Computing is a technology widely used in academia and industry, providing varied services on demand. Blockchain technology was developed initially for the creation of a crypto-currency and nowadays is being exploited for several other applications, such as health, agriculture, IoT and education. Some work initiatives are already taking place with the integration of these two technologies, either for research or for cloud service provision. This article aims to present a preliminary discussion on some aspects of integration between blockchain and cloud computing. Contributions of this paper include: (i) presentation of two integrated commercial cloud computing and blockchain environments; and (ii) some research opportunities on the use of both environments.**

***Index Terms*—cloud computing, blockchain, integrated environments**

I. Introduction

Cloud Computing is a set of enabled network services, providing scalability, quality of service, inexpensive on-demand computing infrastructure and can be accessed in a simple and pervasive manner [1]. Cloud computing is a pay-as-you-go mode of providing scalable, flexible, and shared computing services (e.g. servers, storage, networks, software, analysis, intelligence, etc.) to users over the network [2]. It is attractive to business owners because it has several compelling features: high scalability, high reliability, on-demand services, easy access and low cost. Examples of cloud providers are Amazon AWS, Microsoft Azure, and Google Cloud.

Blockchain technology was developed initially for the creation of a crypto-currency. However, it has been exploited for several other applications. Moreover, blockchain has become attractive for several kinds of research nowadays because of security features [3], becoming a research object. Blockchain technology has attracted interest due to the shared, distributed, fault-tolerant database that all network participants can share the ability to nullify opponents by taking advantage of the honest nodes' computational resources and the information exchanged is tamper resistant [4].

When using blockchain technology, data is stored redundantly in several locations, in a data structure known as distributed ledger [5]. Any changes in the distributed ledger are executed by transactions, and they are kept consistent between all network participants using consensus algorithms. Building a blockchain-based applications enables the creation of software that is executed in a decentralized, transparent, trustless, and tamper-proof environment. These applications are named DApps, for decentralized applications [6].

Some work already discusses blockchain and cloud computing utilization, such as security [7], decentralized applications [8], virtual machine migration [9], and resource scheduling [10]. In addition, there is also the concept of Blockchain-as-a-service (BaaS), the combination of cloud computing and blockchain. It allows users to leverage cloud-based solutions to build, host and manage their own blockchain applications, smart contracts and functions on the blockchain [2]. Examples of BaaS are the services provided by AWS Blockchain and Azure Blockchain.

This article aims to present a preliminary discussion on some aspects of integration between blockchain and cloud computing. The remaining of the article is divided into the following sections: section II presents a brief background; section III describes an example of integrated use of technologies; section IV discusses some aspects of integrated applications and research opportunities; finally, section V presents the conclusions of this work.

II. Background

A. Cloud Computing

According to the National Institute of Standards and Technology (NIST) [11], cloud computing is defined as an evolving paradigm. Their definitions, use cases, technologies, problems, risks and benefits will be redefined in discussions between the public and private sectors, and these definitions, attributes, and characteristics will evolve over time. In dealing specifically with the definition, a broadly accepted definition is not yet available. NIST presents the following definition for cloud computing: "cloud computing is a model that enables convenient and on-demand access to a set of configurable computing resources (for example, networks, servers, storage, applications, and services) which can be quickly acquired and released with minimal managerial effort or interaction with the service provider." In this paper, we consider the presented view of NIST, which describes that the cloud computing model consists of five essential characteristics, three service models and four deployment models [11].

Cloud computing has essential features that taken together exclusively define cloud computing and distinguish it from

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other paradigms [11]. These features are: self-service on demand, wide access, resource pooling, fast elasticity, and measured service. The cloud computing environment is composed of three service models. These models are important because they define an architectural standard for cloud computing applications. These models are: Software-as-a-Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS). Finally, cloud computing deployment models can be divided into public, private, community, and hybrid cloud.

B. Blockchain

A blockchain could be stated to as a distributed ledger, where data and transactions are not under the control of a third party [2]. Any transactions in a blockchain are completely recorded in the public ledger in a permanent and verifiable manner. Examples of blockchain solutions are Ethereum and Hyperledger. All of them have some common elements as follows [2]: (i) Replicated ledger: All nodes in a blockchain network securely store transactions history. The latest transactions are packaged into a block and then the block is append-only with immutable past. All transactions in the blocks are distributed and replicated among all nodes, being part in the network; (ii) Peer-to-Peer network: All nodes share a public ledger without a centralized control actor. All nodes are connected through a peer-to-peer network, and transactions and blocks are synchronized through this network; (iii) Consensus: Before the insertion of the blocks into the chain, all nodes on the network need to reach a consensus on the validity and the order of transactions within the blocks. The most representative consensus algorithm in public chain is Proof-of-Work, used in Bitcoin; and (iv) Cryptography: Security in a blockchain is based on the knowledge of cryptography. In a blockchain network, the integrity of transactions supports digital signatures and proprietary data structures (for example, Merkle tree in Bitcoin, Merkle Patricia tree in Ethereum). Moreover, the transactions authenticity is supported by digital signatures and the transactions privacy is supported by asymmetric cryptosystem.

Blockchain is a block sequence containing the complete transaction log, acting as a public book, maintained by multiple nodes in a network [12]. Each node contains the identical copy of this ledger. Each block is a logical sequence of transactions, which are permanent, transparent and unchanging records [13]. Moreover, each block contains a timestamp, the hash value of the previous block (parent), and a nonce. A nonce is a random number to verify the hash. This concept guarantees the integrity of the entire blockchain to the first block, named as genesis block. Hash values are unique and thus fraud can be effectively prevented, since changes to a block in the chain would immediately change its hash value [14]. Figure 1 represents a blockchain with the newly validated block pointing to the immediately preceding block generated. Each block in the chain confirms the integrity of the previous one, and all the path back to the first block, called the genesis block [12].

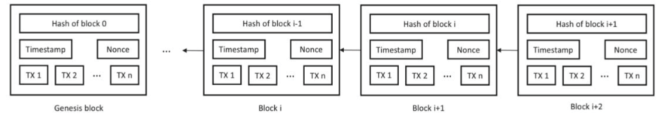

Fig. 1. Example of blockchain and its blocks [3] [15]

III. Examples of Integrated Cloud Computing and Blockchain Environments

A. AWS Blockchain

Amazon has a blockchain service called AWS Blockchain [16]. Basically, AWS Blockchain works with templates, providing a practical way to build and deploy secure blockchain networks using open source frameworks. These templates allow the user to focus on building blockchain applications. AWS Blockchain models deploy the blockchain structure chosen in containers as an Amazon Elastic Container Service cluster or directly into an EC2 instance running Docker. The blockchain network is created on its own private network, allowing the use of its subnets and access control lists. In addition, the user can assign permissions to restrict which resources can be accessed.

Templates can also be applied to different blockchain infrastructures, with two available models: AWS Blockchain for Ethereum and AWS Blockchain for Hyperledger Fabric. The AWS Blockchain template for Ethereum utilizes Ethereum, which is an open source blockchain framework from the Ethereum Foundation that allows to write blockchain applications that run exactly as scheduled without any downtime, censorship, fraud or interference from third parties. It is used when the user need to perform peer transactions on the Ethereum public network, create a new public network, or use Ethereum's Solidity smart contract language. The AWS Blockchain model for Hyperledger Fabric, on the other hand, uses Hyperledger Fabric, which is an open source blockchain framework from the Linux Foundation that allows to write blockchain applications and provides access control and permissions for blockchain data. It is used when the user wants to create a private blockchain network or limiting transactions that can be viewed by individual parties.

Figure 2 shows the flow of model usage in the AWS Blockchain. In this flow, the user initially selects the model, then the deployment platform, the network structure, and finally the applications. As a benefit, AWS Blockchain promotes deployment speed, choose from popular blockchain frameworks (Ethereum and Hyperledger Fabric), tools for managing and paying as you go.

B. Azure Blockchain

Microsoft has a blockchain service, which uses its cloud resources, called Azure Blockchain [17], with the idea of being a foundation for cloud blockchain applications. The user can create, control and expand blockchain networks at scale, simplifying the formation, management and governance

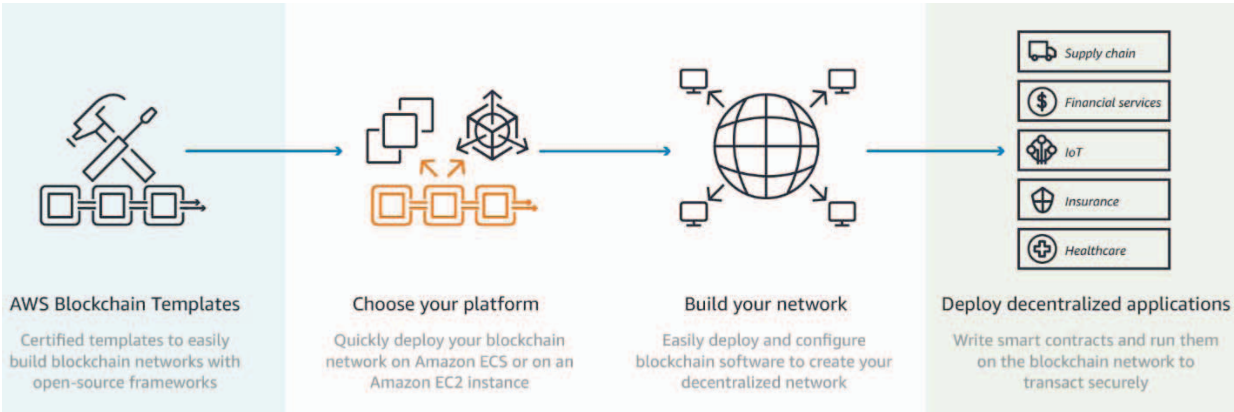

Fig. 2. AWS Blockchain operations Flow [16]

of consortium blockchain networks so the client can focus on business logic and application development.

Some features are: deployment of easily managed blockchain networks; scale control with codeless consortium management and internal governance; building blockchain applications with confidence using tools; and capturing and storing ledger data out of the chain, using the blockchain data manager.

Blockchain network deployment and operations are through the creation and configuration of the blockchain infrastructure. For internal consortium management, complete node management and consortium control must be achieved at scale. Modular controls offer easy member integration, codeless permission, and simplified policy enforcement.

In blockchain data publishing, the user can create end-to-end solutions using the blockchain data manager. This provides flexible, reliable and scalable data flow and application integration. There are functions for monitoring smart contracts, reacting to transactions and events, and transmitting data in the chain to out-of-chain data stores.

Figure 3 shows a flow for publishing data with services and different databases. Highlighting the Blockchain Data Manager component, which captures, transforms, and delivers Azure Blockchain Service transaction data for a variety of Azure events, providing scalable, reliable blockchain ledger integration with Azure services.

IV. Discussion and Research Opportunities

A. Integration Aspects

Cloud computing environments naturally have a variety of tools and services, whether for application development or infrastructure. And also the integration between these services takes place. With blockchain as a service, the ability to integrate environments and applications tends to become more common once the benefits of technology are known.

However, as the number of technologies is also large, there is a risk of integration problems. An example is some PaaS service providing some programming language for the rapid development of an application that uses blockchain features.

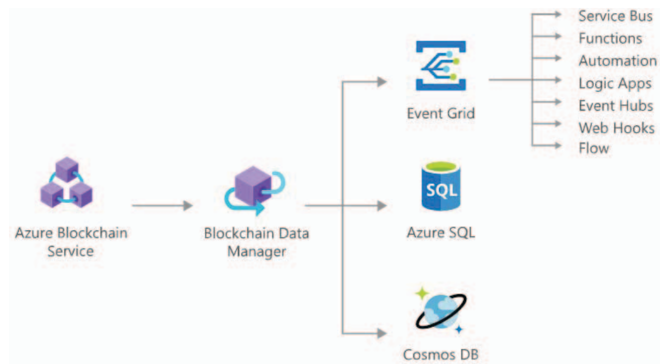

Fig. 3. Flow for publishing data in Azure Blockchain [17]

The integration points are many, requiring attention to the solution architecture.

B. Modeling

Just as the amount of services is vast in cloud computing environments, and blockchain applicability in many areas also grows, the way in which applications are modeled must be handled with care.

Business services often have tools for modeling and deploying services, from infrastructure to end application. This may contribute to the speed of development, but it is still necessary to mature in these tools to make it easier for the user to create their own applications.

The use of blockchain design patterns can help in modeling systems. Examples of patterns are in [18]. The notation to be used should also provide mechanisms for modeling static and dynamic aspects of the proposed applications.

C. Environment Quality and Attribute Metrics

One of the features of cloud computing is the measured service, which means that systems automatically control and optimize the use of resources by means of a measurement capability. The use of resources can be monitored and controlled, allowing transparency for the provider and the user of the service. To ensure Quality of Service (QoS), it is possible to use a Service Level Agreement (SLA) approach [11]. The SLA provides information about levels of availability, functionality, performance, or other attributes of the service such as billing and even penalties for violations of these levels.

Services using blockchain should also be monitored, as there is a financial cost involved, as well as every cloud computing service that pays for usage. In all of these situations, appropriate metrics should be identified.

D. Smart Contracts and Cloud Computing

Smart contracts and blockchain are revolutionizing business by removing intermediaries [8]. Farther, they have the potential to change the current cloud/fog markets, by enabling the creation of a blockchain-based decentralized cloud solutions to face these problems.

The development of blockchain-based solutions for cloud computing has only recently started and focuses on commercial targets [8]. In this context, several challenges arise, such as: performance analysis of environments, security of access, data management, and cost effectiveness of applications running inside the blockchain and outside the blockchain..

V. Final Remarks

Cloud computing and blockchain applications are starting to be used together. The use of both appears to be beneficial for several areas, such as health, education and logistics. Both have several technologies for full use, and this entails challenges, especially to model architectures that contemplate both environments and the exchange of data between them.

A study of the quality of the two environments working together is an interesting subject for research. Functional and non-functional requirements must be adequate to benefit from both technologies. This promotes more testing at various levels.

As future work, we intend to explore Amazon and Azure blockchain environments, understand their architecture and components, and model prototypes to analyze the performance of applications deployed in such environments.

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