EduBloud: A Blockchain-based Education Cloud

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***Abstract*—Cloud service for education purpose is the critical infrastructure for the smart campus. The state-of-the-art education clouds are usually developed and maintained by individual schools. The isolation nature makes these data being tampered easily, which leads to malicious tampering and information fragmentation. The blockchain is a perfect technology to address these issues. By leveraging the advantages of the public blockchain, consortium blockchain, and private blockchain, we propose EduBloud, a heterogeneous blockchain system empowered education cloud. The system showed higher reliability, lower latency, higher data throughput, and better economic efficiency than homogeneous blockchain implementations.**

***Index Terms*—cloud, blockchain, education, smart campus**

I. INTRODUCTION

With the development of big data, education cloud became the infrastructure of smart campus, which is considered one of the core tasks in information construction of higher education. On the one hand, it encourages innovations in teaching and management. However, most education clouds still use traditional methods to handle data management and transactions processes, which exist significant problems on efficiency and security. The difficulties traditional education faced with mainly include: 1) Scattered data: The data system of each school is independent from others. For example, in many regions, the file system of kindergartens is separated from that of primary schools. Junior high schools, senior high schools and universities all have exclusive file systems respectively; 2) Malicious temper: the file system that schools use mostly nowadays is a centralized database which managed by humans so it is possible that the data is modified or controlled by authorities. For example, surveillance video is essential for school security. However, the situation that important videos gets lost and the person in charge shirk responsibilities sometimes happens; 3) Inconvenient delivery: the recording forms of files, which is scattered and in hard copy (or in the semi-digital form), have brought significant troubles to quick delivery. Once the files are needed, the only way to access is going to the corresponding institution such as school, talent market, and Bureau of education. Besides, delivery of transcripts and diplomas across borders is even more time and labor consuming; 4) Inconvenient inquire: it is difficult for the recruit units to inquire since there are only limited ways; 5) Academic cheating: due to the low cost and considerable income, academic cheating happens globally. In 2017, the director of admissions at the Massachusetts Institute of Technology (MIT) was accused of holding fake diplomas for nearly 30 years.

The blockchain system [1], born with the feature of resistance to data modifications, has introduced decentralized applications (Dapps) [2] to many domains. The blockchain technology is suitable to solve problems in education cloud. In October 2016, the white paper on blockchain technology, development, and application in China announced by China's Ministry of Industry and Information Technology claimed that characteristics of the blockchain, such as transparency and immutability, are entirely suitable for storing students information and certification [3]. For example, it can be used in terms of students credit management, enrollment, employment, academic certification, asset certification, industry-university cooperation, etc., which has a significant influence on education. Based on blockchain technology, we can develop a reliable, integrated, efficient, traceable and secured cloud system for data management and information processing.

However, due to the decentralization nature and proof of work (PoW) overhead, the classic public blockchain is incapable to support the functionalities of education clouds. To address this issue, we propose EduBloud, a heterogeneous blockchain based education cloud infrastructure, to facilitate the digital and distributed management of students diplomas and personal files. By leveraging a heterogeneous blockchain, our system provides high throughput, low operational cost, and reliable education cloud services for smart campus. The remainder of this paper is organized as follows. We reviewed the related work of the education system with blockchain in Section II and presented the overview of the framework in Section III. We then present the technical design in Section IV. Based on empirical data, the estimations and evaluations are conducted in Sections V. Section VI concludes this paper.

II. RELATED WORK

A. Types of Blockchains

The existing blockchain systems can be categorized into three types from the perspective of node participation. *1) Public Blockchain*: also known as permissionless blockchains, since there is no permission required to join the public blockchain network. Representative public blockchains include Bitcoin and Ethereum [4]. *2) Consortium Blockchain*: known as permissioned blockchains, since there are restrictions on the network participators. To join a conventional consortium blockchain, invitations or authentications are required. Hence, it is a specific blockchain that multiple authorized nodes maintain a distributed shared ledger with a moderate cost [5]. Normally it is used in the cooperation scenarios among business organizations. Hyperledger Fabric[1] initially contributed by IBM is a typical consortium blockchain, and has chosen Practical Byzantine Fault Tolerance (PBFT) as the consensus algorithm. *3) Private Blockchain*: used within an organization or a company. Only members of the organization can access it. Two popular private blockchain platforms are private deployed Hyperledger Fabric and Ethereum [6]. The system designers need to consider their trade-offs among different blockchains when integrating them to their cloud services [7].

B. Heterogeneous Blockchain

The heterogeneous blockchain is a more valuable architecture for the heterogeneous environment of the world. An interactive multiple-blockchain architecture [8] for exchanging information across heterogeneous blockchain has been studied. Factom [9], Tangle [10], Side-chain [11] and Cosmos [12] attempted to solve out the problems of global consistency, high trading volume and interoperability that are caused by the heterogeneous blockchain respectively. Casper [13] and Polkadot [14] proposed a new protocol to enhance the scalability of the heterogeneous blockchain. [15] proposed a heterogeneous blockchain application in multi-energy integration, which can effectively support the innovative service pattern of the energy industry. [16] proposed a heterogeneous intelligent transportation system(ITS). The first part of this work uses the concept of heterogeneous blockchain to simplify the distributed key management in VCS domains, which performs better than the centralized key management in the key transfer. [17] implemented medical data sharing and access system based on heterogeneous blockchain, which can control collaborations among different blockchains through smart contracts. IoTex [18] established an auto-scalable and privacy-centric blockchain infrastructure for the Internet of Things (IoT) based on the blockchain-in-blockchain technology architecture. Block Collider [19] is a protocol of heterogeneous blockchain, which enhances the cooperations among multiple blockchains.

C. Blockchain-based Education Cloud

The open validation, transparency, and unchangeable nature of blockchain technology fit well with applications in higher education. Nicosia [20] is the first university which leverage the bitcoin blockchain technique to manage the students' certification from Mooc. Holberton [20] also store the academical degree so the user can query the education experience, personal programs with id. EduCTs [21] propose a credit transfer system based on Ark Platform across the globe. In 2016, Sony proposed Sony Global Education program, recording academical level [22]. The MIT Media Lab also began issuing digital certificates system to the public in early 2016, using cryptography to ensure certificate reliability. Central University of Finance and Economics Using blockchain technology to help students record relevant documents, greatly facilitating students and enterprises to obtain academic credentials and awards The situation, etc., reduce the cost of recruiting jobs and recruiting. [23] proposed the use of Hyperledger Fabric technology to implement a licensed blockchain based School Information Hub (SIH) student information center to prevent data fraud and improve the accuracy of decision-making. [24] proposed a blockchain for education platform established by using Ethereum platform to realize the security protection and management of academic certificates or other data, satisfying the demands of students, companies, educational institutions, and certification bodies. However, blockchain technology can provide the authenticity of data (achievements, credits) in the field of education, but the technology itself does not ensure data validity [25].

[1]https://www.hyperledger.org/projects/fabric

III. System Overview

As a disruptive technology, blockchain is leading the reform in technologies globally. Combined with the decentralized storage, peer-to-peer (P2P) network and different kinds of consensus model, the data and smart contracts in the blockchain system are featured with a series of characteristics such as immutable, traceable, decentralized, anonymous and transparent, etc.

A. Objectives

The private data of students will be stored in the private blockchain deployed by each campus. Meanwhile, the commitment of students' private data and the shared education record which the Bureau of Education and recruiters might acquire should be uploaded to the consortium blockchain. A commitment scheme is a cryptographic primitive that allows one to commit to a chosen value (or chosen statement) while keeping it hidden to others, with the ability to reveal the committed value later [26]. The commitment is normally a SHA-256 hash value of data. The campus, Bureau of Education and recruiting unions are independent nodes forming the consortium blockchain. To ensure the reliability and immutability, the commitment of all data in the consortium blockchain should be committed to the public chain periodically. Regarding the quality of service (QoS) restrictions, the overall delay of the proposed system should be restricted within 3 seconds, and the throughput should be more than 100 TPS (Transaction per Second).

B. Framework

As illustrated in Fig. 1, the architecture of our system is divided into three layers. The bottom layer is the blockchain system. On top is the fundamental management system and the upper layer is the business application platform.

1) Blockchain Layer: The blockchain-based cloud system manages the nodes of the private blockchain, consortium blockchain, and public blockchain. Meanwhile, it also provides API for data storage and access.

Different blockchains store different data. Data of one student will be stored in one block in the private blockchain. All blocks storing students' information form each private blockchain of their campus. The schools, Education Bureau,

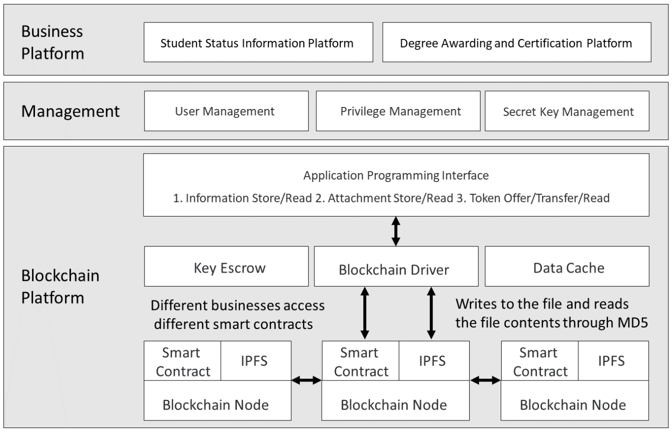

Fig. 1. Framework for EduBloud System

recruiters, and relative organizations share one consortium blockchain and each of them deploys one node. All nodes on the consortium blockchain should reach the consensus for each record. There are two kinds of data on the consortium blockchain. The first kind of data is commitment. To ensure the reliability of data on private blockchains and prevent the data being maliciously modified, the commitment of the data will be saved in the consortium blockchain. The second kind of data is a small portion of data such as certifications. This kind of data which is used to transfer among different organizations. Considering the cost, efficiency, and immutability, only the commitment of the data on the consortium will be uploaded to the public blockchain regularly every day.

We use IPFS for block data storage since it has good scalability and high efficiency in storing big data. In our system, IPFS is designed to store attachments. Our blockchain system also provides a mechanism for depositing secret keys, which provides a method for users who are reluctant to save their secret keys. The secret keys are stored in the platform in an encrypted and distributed way. As a result, the whole system is highly secured and nonvolatile.

2) Management Layer: The fundamental management system consists of the user management system, privilege management system and file management system. Different users have different permissions according to their privileges. For example, teachers can modify students score information and regulators can modify students daily performance information. Schools can modify students reward information. However, teachers are not allowed to modify students reward information.

3) Business Layer: The application platform mainly consists of front-end pages for users to manipulate.

IV. System Design

Our work has two main research topics: 1) Heterogeneous blockchain based data management: By leveraging the heterogeneous blockchain in system design and development, we improve system efficiency and reduce system cost. 2) Payment channel empowered transactions: By leveraging smart contracts, we construct an automatic information processing and trading system.

A. Heterogeneous Blockchain Based Data Management

Our data management module uses the heterogeneous blockchain which combines the private blockchain, consortium blockchain, and public blockchain. Based on the Ethereum and the HyperLedger, our team members customize a reliable private blockchain and develope a three-layer data management system for the heterogeneous blockchain. The architecture of our system is shown in Fig. 2.

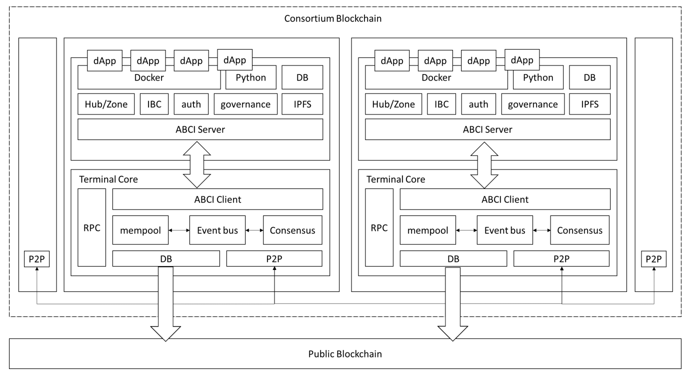

Fig. 2. Architecture for EduBloud System

The system includes: In our architecture design, private blockchain communicates with consortium blockchain through RPC. After storing data into the private blockchain, nodes of private blockchain synchronize data to nodes of consortium blockchain according to their need. As for the remaining data, the commitment of it is synchronized to the consortium blockchain at a time interval. Besides, the commitment of data stored in consortium blockchain is synchronized to the public blockchain once a day.

The modules depicted in the architecture is described as follows. *Public blockchain*: Uses the Ethereum which is a widely recognized public blockchain platform and uses Solidity to develop smart contracts on blockchain for synchronizing public data periodically. *Consortium blockchain*: Based on the HyperLedger platform. *Docker Smart Contract*: A smart contract platform used by Hyperledger Fabric and supports smart contracts using Go. *Auth*: An authorization control module, making sure that only member nodes in the consortium blockchain can access and synchronize data. *Governance*: Management module of members in consortium blockchain, which is responsible for the management of members joining and quitting mechanism. *Private blockchain*: Based on the HyperLedger platform. *White list*: Private blockchain uses a whitelist to control access of its nodes and does not allow external nodes to join. *Python Smart Contract*: Private blockchain support python smart contract. *RPC*: Remote procedure call, a technique for requesting from a remote computer program through the network and enables remote communications and mutual calls between different systems in distributed system architecture. It is mainly used for internal and external calls between the private blockchain and consortium blockchain. *ABCI Client/Server*: Application Blockchain Interface defines a standard blockchain application interface (BeginBlock, DeliverTx, CheckTx, Commit, EndBlock), ABCI Server responsible for the implementation of the interface. *Mempool*: Memory pool, the cache used for the committed transaction. *Event Bus*: Event bus, be responsible for event notification between consensus module and memory pool. *BFT consensus*: Byzantine fault tolerance consensus algorithm, consensus algorithm used by private blockchain and consortium blockchain and protects one-third of the nodes against the Byzantine attacks. *DB*: Used to store block data of blockchain. *IPFS*: InterPlanetary File System, used to store large attachments. *Hub*: Used for transitions. Zone represent different blockchain platform.

V. Performance Evaluation

A. Monetary Cost Analysis

We first analyze the monetary cost of the proposed system. Table I shows the Total Ownership Cost (TOC) and Operating Cost for traditional data-center-based centralized systems and blockchain-based distributed systems, respectively.

TABLE I
COMPARISON OF COST IN DIFFERENT CHAINS

Cost	Index	Centralized	Decentralized	Heterogeneous
Total Owner Cost (TOC)	Cache	2 copy	$\geq$3-4 copy	$\geq$2 copy
	Computation	2	1	1
	Network	1	1	1
	Facility	1	$\leq$1	$\leq$1
	Security	1	$\leq$1	$\leq$1
	Maintenance	1	$\leq$1	$\leq$1
Operation Cost	Store/Access	$\geq$2	$\geq$3-4	>2
	Calculation	2	$\geq$4	>2
	Communication	2	$\geq$8-10	>2

1) Total Ownership Cost: The TOC mainly includes hardware and software inputs (storage, computing, network, infrastructure, security facilities) and human resources (maintenance personnel). The centralized system usually uses one running data plus one backup data for the data storage. The blockchain-based distributed system often saves three to four copies of the data in the whole network. In terms of computing resources, the centralized system should have high redundancy requirements to respond for access peak. In contrast, blockchain-based distributed architecture can spread access shocks to other nodes, so the computing power of a single node does not need to be equipped with additional redundancy; in terms of network investment, the network trunk bandwidth of centralized systems usually equips with the highest configuration. The blockchain-based distributed system requires less bandwidth than the centralized system, which is mainly due to the mechanism for data asynchronous transmission and verification. The investment in infrastructure and safety facilities can be linked to each unit of equipment by a factor and is therefore only relevant to the total equipment size. Due to the architectural characteristics of the blockchain-based distributed system, the single node has simple requirements for data recovery and service continuity. In fact, it is possible to reduce the investment in infrastructure and safety facilities. Most of the node maintenance is about simple reset and synchronization, so the maintenance personnel is less invested than centralized systems.

TABLE II
THE INFORMATION DETAIL OF APPLIED SCENARIOS

Total Number of students	2209200
Number of Campus	2551
Number of students Per Campus	866
Data Size per student On Private BC	300
Data Size per student On Consortium BC	15
Students Data Frequency	1000
Data Publish Frequency	1
Tx Fee	0.009
Number of Bureau	10
Number of Node	2561

2) Operation Cost: Operating cost, in detail, is the consumption of accesses, calculations, and communications. The blockchain-based distributed system is more than twice as large as the centralized system in access operations cost, several times in computational costs, and more multiples times in network computation costs. These consumptions are expressed as the average operating occupancy of the physical device, which is ultimately reflected in additional power consumption. In a blockchain-based distributed system, the average operating occupancy of physical devices is higher than that of centralized systems because they have to communicate constantly to reach an agreement. But the final calculation is that the difference in power consumption is within 5%. Cloud platforms usually do not use power consumption as a charging parameter. Therefore, when a cloud platform is used as a source of physical facilities, the extra operating cost of the equipment is limited.

A convenient public payment channel is provided on the heterogeneous blockchain, with a single payment cost of 0.9 cents (according to the current Ethereum system). And we have designed a payment gateway implemented with smart contracts that can support large-volume online payment transactions, and as the amount of payment transactions increases, the cost of finishing a single payment transaction is lower. The heterogeneous blockchain can also build a payment system at the level of the consortium chain. As the cryptocurrency supervision policy becomes more precise and the public acceptance increases, it will be a topic worthy of further study.

B. Performance Comparison

In this work, we perform a case study base on the data set illustrated in Table II. The data regarding schools and students come from the Shenzhen Municipal Education Bureau's "Basic Situation of Education Development in Shenzhen in 2018".

Based on this information, we can estimate the difference in storage scale between the heterogeneous blockchain and the non-heterogeneous blockchain. It is found that the heterogeneous blockchain can effectively reduce the total storage cost shown in Table III.

TABLE III
THE STORAGE SPACE OF DIFFERENT CHAIN

	Heterogeneous Blockchain (EduBloud)	Consortium Blockchain
Total Storage (M)	1458624300	2651040000

We established an experimental heterogeneous blockchain system, EduBloud, which was compared with the private blockchain, the consortium blockchain, and the public blockchain system represented by Ethereum. Table IV shows the comparison results. The throughput of fabric as the private and consortium blockchains can easily reach 200 TPS or more. Relatively, the throughputs of public blockchain systems are usually not high. For example, the throughput of the Bitcoin system is only 7 TPS, and the Ethereum system has two to three times performance improvement. The proposed experimental system can also reach 143 TPS. From the perspective of cost, the cost of EduBloud system is slightly higher than that of the consortium blockchain system but far lower than that of the public blockchain system. Transactions delays have similar trends for EduBloud system.

In terms of the system security and reliability, we also compare three aspects of these four systems in Table IV, including the privacy protection capability, tamper resistance ability and system failure possibility. Here, the system failure protection capability refers to the ability of the system running properly as usual while losing some of the nodes participating. Apparently, overall the heterogeneous blockchain outshines the other systems as a whole. It has excellent privacy protection capability comparable to the private blockchain system and the tamper resistance ability comparable to the public blockchain system. In terms of system failure protection, although it does not perform as well as the public blockchain, it performs much better than the private blockchain and consortium blockchain.

For EduBloud, all data must be saved to the private blockchain. Part of the data is selected and saved to the consortium blockchain and the commitments of all data is saved to the public blockchain at regular time intervals. We modify two performance factors in our experiments, which are the proportion of data saved to the consortium blockchain and the frequency of saving commitments to the public blockchain. The following experiments are carried out from the perspectives of throughput, time delay, and cost with different sizes of data saved to the consortium blockchain and frequencies of saving commitments to the public blockchain. We suppose the total amount of data of students per day is 10G, and the block size does not exceed 2M. The experiment results are shown in the following figures.

TABLE IV
COMPARISON OF PERFORMANCE AMONG DIFFERENT CHAINS

Index	**Private (Fabric)**	**Consortium (Fabric)**	**Public (Ethereum)**	**Heterogeneous (EduBloud)**
Cost	low	mid	high	mid
Delay(s)	<0.1	1∼2	12	<4.5
TPS	>300	<200	15∼25	143
Privacy	high	mid	low	high
Tamper Resistance	low	mid	high	high
Failure Rate	high	mid	extremely low	low

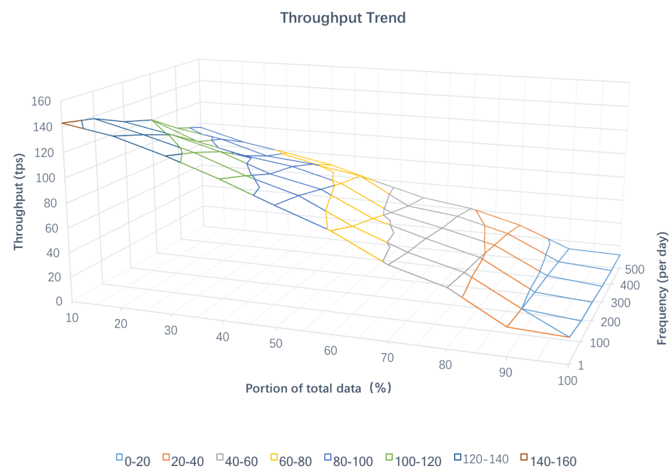

Fig. 3. Throughput

Fig. 3 demonstrates the throughput trend in different portions of data and various frequencies. The larger portion of data put on consortium blockchain, the smaller the throughout is. Meanwhile, the higher frequency that the commitment is uploaded to the public blockchain, the smaller the throughout is.

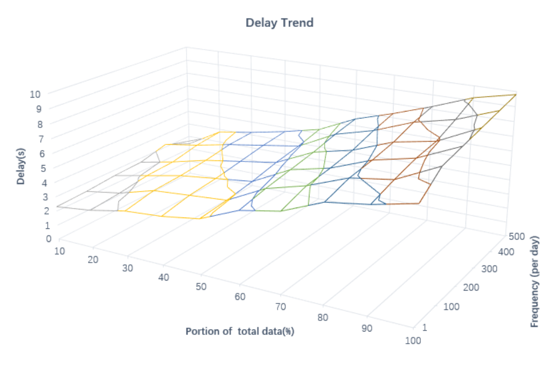

Fig. 4. Delay

Fig. 4 indicates the delay trend in different portions of data and various frequencies. The delay increases as the portion of data increases or the frequency increases.

From the perspective of the monetary cost, the cost of the private blockchains can be neglect, since they don't need to

Fig. 5. Monetary Cost

reach consensus with other nodes, which is the major cost of blockchain systems. In contrast, the price of the consortium blockchain is set to 0.01 $/MB data, while the price of the public blockchain is set to 0.09 $/KB data. We assume that each hash data from consortium blockchain to the public blockchain requires 1 KB writing to the blocks. According to Fig. 5 , as the proportion of data stored in the consortium blockchain increases and the frequency of commitments saved to the public blockchain increases, the monetary cost increases.

From the estimation, we would like to propose 10% of the data to be stored in the consortium blockchain and one hash value will be written to the public blockchain once a day in the final real project.

VI. Conclusion

This paper presents the design of the heterogeneous blockchain system named as EduBloud, which aims to ameliorate the information system for educational purpose. The proposed system combines the advantages of three types of blockchains. According to our numeric analysis in the case study, EduBloud will secure the education records of students and provide efficient delivery of information among parties. Furthermore, it achieves better performance in terms of monetary cost, throughput, and latency than homogeneous blockchain architecture.

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