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Birthday: 1999/6 | Male | Hometown: HUNAN

EDUCATION

Chinese University of Hong Kong, Shenzhen (CUHK-Shenzhen) *Sep 2017 - Jun 2021*

Bachelor in Computer Science and Engineering *Shenzhen*

- GPA: 3.539 / 4.0 (Top 10%)

HONORS & AWARDS

- 10th Undergraduate Research Award *2019*
- School of Science and Engineering Dean List *2018, 2019*

RESEARCH EXPERIENCE

Blockchain-based Toll Collection System *Nov 2018 - Feb 2019*

- Apply blockchain in traditional edge computing fee collection system and test performance in a production environment.
- Publish paper at 2019 IEEE INFOCOM WKSHPS (IECCO) as first author and was Invited for presentation in Paris.

Digital Agriculture Fruits Counting *Nov 2019 - Present*

- Apply Faster-RCNN (object-wise) in fruits counting (single frame) with 90% prediction accuracy.
- Implement semantic segmentation model (pixel-wise) for apples.

Blockchain-based Education Cloud *May 2019 - Aug 2019*

- Collect previous literatures on blockchain education system and perform necessary system throughput test.
- Published paper at Computing, Communications and IoT Applications Conference (ComComAp2019).

WORK EXPERIENCE

Software for Edge and Blockchain Systems (SFENKS) Laboratory, CUHK-Shenzhen *Sep 2019 - Present*

Undergraduate Research Assistant *Shenzhen*

- Conduct research on resource sharing problems and try to solve it by blockchain incentive mechanisms.
- Investigate the relational model of multi-users and multi-edges in edge computing.

Research Institute of Tsinghua University in Shenzhen *Sep 2019 - Present*

Undergraduate Research Assistant *Shenzhen*

- Implement deep learning algorithm (fruits counting, illness prediction) in agriculture.
- Develop a front end visualization interface for sensor data.
- Enable data transferring between raspberry pi and amazon web service.

Institute for Shenzhen Big Data Institute, CUHK-Shenzhen *Jun 2019 - Dec 2019*

Software Engineer , Front-end *Shenzhen*

- Implement frontend interface of query entry by JavaScript.
- Develop a Wechat mini program about smart commutation for 2019 Huawei Data Creativity Competition (rank 9th).
- Reorganize web pages by adopting new visualization framework E-Chart JS.

Tech X Academic Summer Camp *Sep 2019 - Oct 2019*

Academic Leader , Machine Learning *Shanghai*

- Participate in teaching routine (debug students' homework or explain machine learning algorithms concept).
- Provide advice for more than one hundred students on their final programming project.

EdgeToll: A Blockchain-based Toll Collection System for Public Sharing of Heterogeneous Edges

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***Abstract*—Edge computing is a novel paradigm designed to improve the quality of service for latency sensitive cloud applications. However, the state-of-the-art edge services are designed for specific applications, which are isolated from each other. To better improve the utilization level of edge nodes, public resource sharing among edges from distinct service providers should be encouraged economically. In this work, we employ the payment channel techniques to design and implement EdgeToll, a blockchain-based toll collection system for heterogeneous public edge sharing. Test-bed has been developed to validate the proposal and preliminary experiments have been conducted to demonstrate the time and cost efficiency of the system.**

***Index Terms*—edge, blockchain, pricing, system, testbed**

I. Introduction

Cloud computing has transformed everything as a service [1] nowadays. Nevertheless, latency sensitive cloud applications, e.g. interactive multimedia systems, are still struggling from the unacceptable delay introduced by the network round-trip time (RTT). Edge computing [2], an emerging computing paradigm in future 5G network [3], is designed to improve the quality of services (QoS) for time-critical cloud applications, especially in the mobile scenarios. In contrary to the remote cloud server, edge nodes are nearby infrastructures, a.k.a. cloudlet, providing software services to the end users. On the other words, edge serves as an intermediate between a terminal device and the cloud to facilitate computing at the proximity of data sources.

However, the state-of-the-art edge platforms are specifically designed for customized applications, rather than a public service for various applications and distinct user groups. For example, an edge node deployed for power plants will not handle video processing requests from a mobile game player, even it has been staying in an idle status for a long time. The isolation among different applications significantly reduces the utilization level of edge resource, which still requires continuous maintenance work. Despite security considerations, one critical issue in preventing public edge resources sharing is the lack of motivation for the edge infrastructure provider. An incentive mechanism is still facing challenges and technical issue from a real-world implementation. First, there is no public third-party trustworthy proxy to collect toll fees for multiple edge service providers. The heterogeneous nature of edge deployments requires a transparent resource bidding platform operated independently. Second, the toll fee for a general service request is relatively small. It may be hard to use legal tender for resource pricing. Third, distinct edge platforms may adopt different pricing schemes and credit systems, which prevent the resource consumers from leveraging available edges nearby.

On the other hand, the blockchain system [4] has introduced a transparent, trustworthy and unformed ecosystem for multiple independent parties. This feature makes it a perfect solution to the toll collection problem in heterogeneous public edge sharing. The immutable and open source smart contracts [5] driven by blockchain enables a transparent profit distribution scheme among multiple edge service providers in an autonomous manner. In addition, by leveraging cryptocurrency, the edge nodes from multiple service providers are able to use a unified, fine-granularity, and transparent pricing method to charge users. From the users' perspective, it is convenient to spend one cryptocurrency in consuming resources from multiple parties, which highly increase the availability of edge services. In fact, the blockchain-based toll system can minimize the cost for both providers and the users, given the business rules are well-defined: there will be no centralized operators to pocket the difference as its profit.

Nevertheless, existing blockchain systems are still in their preliminary stages. Most well-known blockchain systems are suffering from the high cost of gas fee and unacceptable latency introduce by the Proof-of-Work (PoW) [6], while the others, who minimize the overhead by adopting other consensus models (e.g., Delegated-Proof-of-Stake from EOS[1]), are not well recognized as full decentralized platforms. This imposes a big challenge for the toll collections systems for frequent but small amount transactions, e.g. the one we are proposing. In this work, we design and implement EdgeToll, an open source toll collection system for heterogeneous public edge sharing. By leveraging the technique of payment channel, EdgeToll provides a transparent, quick and cost-efficient solution to encourage participation of edge service providers.

The remainder of this paper is organized as follows. We reviewed related work in Section II and presented the overview of the proposed system in Section III. We then present the technical design and test-bed implementation in Section IV and Section V, respectively. Based on our development, the

[1]https://eos.io/

experiments are conducted to validate our system in Sections VI. Section VII concludes this paper.

II. Related Work

A. Cloud and Edge Integration

Integrating edge to cloud platform involves a series of research topics in data and computational offloading. Traditional approach offloading schemes adopt virtualization techniques to host multiple copies of virtual machines in both cloud and edges [7], while another group of researchers has investigated the possibility of dynamic code partitioning [8] [9]. However, despite the form of offloading, the edge nodes intrinsically provide resource services for end users through direct network connectivity. In this work, we assume the end users are requesting micro-services installed in the edge nodes to simplify our model.

B. Decentralized Applications and Payment Channel

The blockchain [4] data structure, together with the peer-to-peer (P2P) system and the proof-of-work (PoW) [6] consensus model, makes the decentralized ledger for cryptocurrencies became a reality [10]. Known as Blockchain 2.0, Ethereum [11] was implemented to facilitate decentralized applications (dApps) [12], which have been extended to various areas, including initial coin offerings, social networks, networked games, and IoT. In this work, we write smart contracts to develop a decentralized toll collection system for edge service sharing among multiple parties, which perfectly demonstrate the benefits of dApps. To overcome the long response latency and the monetory costs introduced by frequent transactions, the payment channel [13] technique is designed for "off-chain" transactions, which allow users to make multiple token exchanges with a minimum number of smart contract invocations. The state-of-the-art payment channels can be classified into two types: *uni-directional payment channel* and *bi-directional payment channel*. An uni-directional payment channel only allows single directional transactions, while a bi-directional payment channel [14] allows both parties to send transactions. The duplex payment channel is composed of two uni-directional payment channels, which allows transactions to be sent from both directions.

III. System Overview

In this section, we present the overview for the proposed system. As illustrated in Fig. 1, edge nodes, and end users should register corresponding addresses in the blockchain before they can participate in the proposed system. These addresses, being accessed with the private keys known to their owners, are the destinations of cryptocurrency tokens. From the perspective of the end user, he/she needs to discover nearby edge nodes that provide the services and pay the corresponding cost after the services are delivered. In case of multiple edge nodes available, the user can choose one from these candidates, in terms of their performance and offered price. On the other hand, the edges can select their service recipients from the perspective of task complexity and bidding price, if there are multiple end users competing for the same resources. Note that, all payments should go through a smart contract to guarantee the transparency of the system.

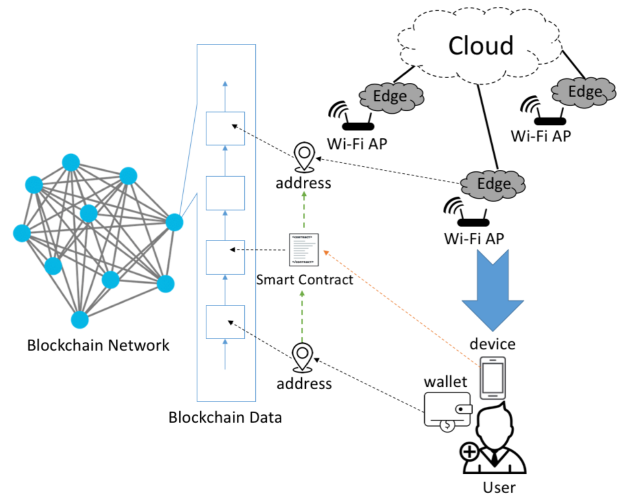

Fig. 1. The System Architecture for EdgeToll

However, the proposed system will consume significant tokens as gas fee when the users pay their toll to the edge nodes. Also, the long transaction delay will also disable high frequent service delivery to the users. Therefore, we may need to create payment channels to minimize the overhead of payment transactions. Nevertheless, it is impossible for a user to establish payment channels to a lot of edge nodes, since there will be another overhead here: the users need to lock certain among of tokens to open the channel, while he/she may only interact with one edge once.

IV. System Design

In order to solve the above issue, we employ an open source proxy as a service matching server and the payment intermediate. The first functionality of the proxy is to match the appropriate service provider and recipient. This process can be optimized with artificial intelligence (AI) algorithms. Alternatively, this process can be a result of a series of competitions and cooperation to be modeled with game theory. In our implementation, the proxy always adopts greedy algorithms to minimize users' cost and maximize the edge nodes' profit under different scenarios. The second role of the proxy is the intermediate of users and the edges. An end user only opens one payment channel to the proxy, while the proxy open payment channels to the edges. Of course, different edge nodes from the same service provider may share the same blockchain wallet, which can significantly reduce the number of payment channels. In this work, since the payment from users to the proxy, from the proxy to the edge service providers, are uni-directional, we adopt the uni-directional payment channel.

Fig. 2 illustrates the sequence diagram for the proposed EdgeToll system. Edges can be deployed by any companies or individuals. For any edge who want to join in the EdgeToll public sharing platform, a registration to the proxy is required as its initialization process. Through the registration, an edge is requested to provide its blockchain address and its IP address: the former one is serving as the destination of toll fees and the later one is how the end user's device identify the edge.

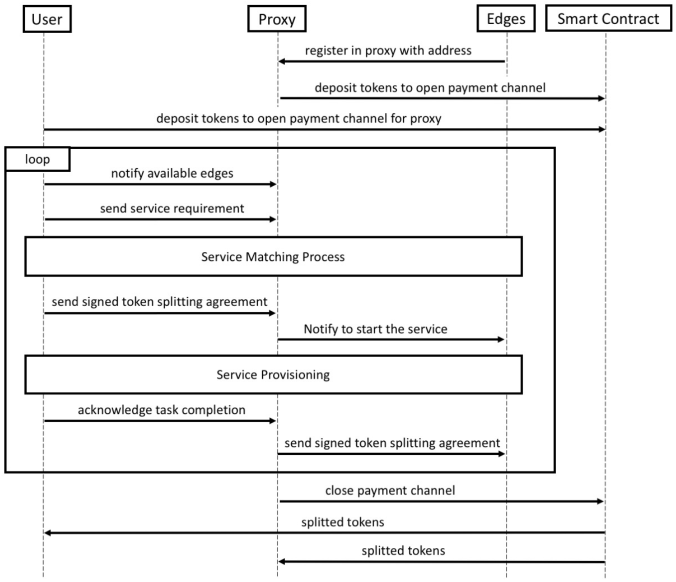

Fig. 2. Sequential Diagram for EdgeToll

After proxy receives edge's address, the proxy will evaluate edge's condition and invoke a smart contract to open a payment channel for the registered edge. The proxy deposits tokens into that contract and set the recipient to be the registered edge so that only the edge can withdraw the token. On the other hand, the end users are usually mobile terminals whose locations are changed over time. Once a user has a demand for edge resources, he/she needs to open the payment channel for the proxy through smart contracts. At the same time, the user also needs to discover nearby edges and notify the list of available candidates to the proxy. After the service requirement is sent from the user to the proxy, service matching process will be conducted to find the suitable pairs. After that, the user needs to sign a signature on an agreement to split the tokens and send it to the proxy. The proxy, the recipient of the signature, can validate the agreement with blockchain data, which is a no-cost operation, since it is a simple blockchain data reading function. After the validation, the proxy notifies the corresponding edge to deliver its service to the user. Once the user acknowledges the completion of service, the proxy will sign its token splitting agreement with the edge to deliver the edge's profit. Note that, this is another signed agreement from the proxy to the edge, which is different from the one the proxy received from the user, though the two agreements may have the same amount of tokens. In practice, the proxy may charge a small amount of transaction fee to cover its operational cost in providing service matching and payment channel intermediate service. However, the transaction fee should be written in an open source program that is agreed by both parties.

After a series of payment, the users, the proxy or the edges may choose to withdraw the tokens by closing the payment channel, which will introduce a gas fee overhead, since it is an on-chain operation. However, all payment channel based off-chain transactions, as depicted in the loop of Fig. 2, are fast data exchange without any cost.

A debatable issue for our design is that we introduced a centralized proxy which handles payments among users and edges, which violates the decentralization spirit of the blockchain. In fact, a simple trick on software engineering can minimize the impact of this concern: the proxy is a completely open source and the proxy code will be hashed and recorded in the blockchain. Any third party can audit the proxy by comparing the hash value of the running system to the blockchain recorded data, thus, maintain the transparency of the system.

V. Test-bed Implementation

A. *Software Architecture*

Fig. 3 illustrates the software architecture for EdgeToll.

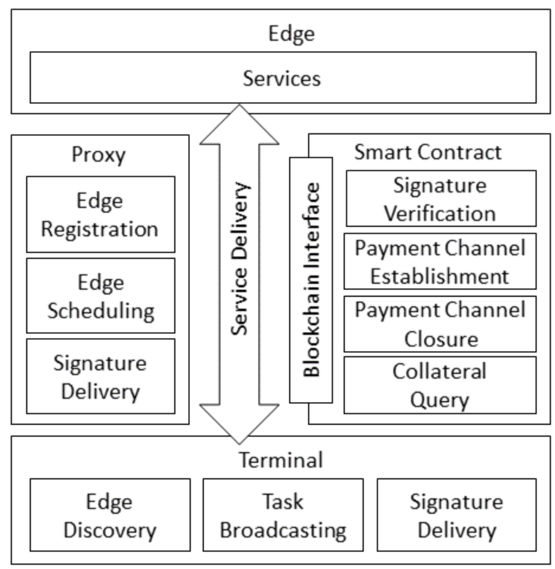

Fig. 3. Software Architecture for EdgeToll System

The *Smart Contract* hosted by Ethereum blockchain provides four major functions to facilitate the payment channel: 1) Payment Channel Establishment: the component for creating a new payment channel. To call this function, the establisher should provide the Ethereum address of channel receiver and sign a transaction to transfer deposit tokens to the smart contract account. The deposit will be locked through the lifetime of the payment channel. 2) Signature Verification: The sender address, receiver address, the value transferred and other signed signature properties should be provided. Keccak256 hash function will hash sender address, receiver address, transferred value together and resulted value will be used to recover the signer of agreement for verification. The return result indicates verification legality in boolean type. 3)

Payment Channel Closure: This module is used to withdraw tokens from the contract account. To verify the qualification of the signature holder, the provided parameters should be the same as Signature Verification. When the invocation happens, the contract will balance the tokens among channel launchers and receivers. Because of the existence of service charge (gas fee), the actual amount receiver obtains is not exactly the same as signature classified. 4) Collateral Query: This module is used to query the balance of existing channels. This qualification-free operation is designed to relieve the distrust of channel receiver. With provided parameters channel launcher address and receiver address, unique channel collateral can be return. If the query result is 0, it implies that the channel between two address has been closed or never exist.

The *Proxy* consists of 3 components: 1) Edge Registration: This component is used for edge devices to register in the database and Ethereum address should be provided. In the real world, the *Proxy* instance will evaluate edges for pricing. But to simplify our model, we fix the deposit amount as 1 ether. The database in *Proxy* will keep a record of the configuration parameters of edges and update dynamical information like location, working status, and memory usage, etc. 2) Edge Scheduling: This component can solve the decision-making problems. Users should provide available edges list attached with task description, which is the result of *Edge Discovery* component in user end. In a future design, the call to this function can match user and edge based on the analysis of data stream from *Terminal* and the dynamical status of available edges, which will provide the user a better resource scheduling. More advanced in further, a task can be decomposed into multiple steps and distributed to heterogeneous edges to improve working efficiency. Our edge selection is determined by the simulated price. 3) Signature Delivery: Users should build payment channel first before the delivery of signed agreement. A verification process will be conducted after the calling from the user. After *Signature Verification* in *Smart Contract* is done, the *Proxy* will call this function again and sign a equal-value signature to edges, which works as a signature delivery intermediate station. If the user set the withdraw pole in request parameters as True, the proxy will close the payment channel immediately.

The *Edge* is the service provider, which may be a container of various functions, such as video surveillance and face recognition. On the other hand, the *Terminal* should contain 3 components: 1) Edge Discovery: the component for discovering nearby edge services. The crucial parameters of edges and description of tasks will be sent to the interface of *Edge Scheduling*. The description of task detail is omitted and all searchable edges have been registered in the proposed simplified model. 2) Task Broadcasting: This component is used to conduct task offloading and type conversion. After the uploading, raw data will be transformed into proper type and then sent to edges for processing. In our work, the input data is an image contains a person. 3) Signature Delivery: The hash value of sender address, a receiver address and amount of tokens will be signed by the private key of the sender. The result of sender address, receiver address, transferred value and three attribute value of signed transaction form a legal signature. The agreement will be delivered to receiver server off-chain.

B. *Enabling Software Packages*

To facilitate the development process, we adopt a series of cutting-edge software to implement constructing components for the system. We select Ethereum[2] as our blockchain platform, due to its popularity and maturity in technical and commercial community. In our implementation, we utilize Truffle Suite[3] to simulate a private blockchain environment for software development and the Rinkeby Testnet[4] to conduct empirical experiments. Ethereum offers Solidity[5], a Turing-complete programming language for smart contract development. With solidity, we implement an uni-directional payment channel to support the transactions among users, edges and, proxy. The smart contract will be invoked by web3.py[6] library, which is a python[7] interface for interacting with the Ethereum blockchain and ecosystem. The reason for choosing web3.py rather than the web3.js framework is that our user client program and proxy server are implemented with Python. To integrate our EdgeToll system to an edge-terminal environment, we leverage the edge platform from Jiangxing Intelligence Inc.[8], an edge computing start-up located in Shenzhen, China. Each Jiangxing edge node provides a Wi-Fi signal as the portal to access its AI applications, including real-time face recognition and positioning. To facilitate dynamical edge service discovery, we adopt pywifi[9], a python library to search available edge services. The list of available edge access points will be updated to the proxy in real-time. After connecting to the edge, the client will initialize a TCP/IP request through the Application Programming Interface (API) offered by Jiangxing edges to submit the user's image in base64 format, and the edge will return the location of the face in the image in a JSON file[10].

VI. Experiments and Analysis

In this section, we validate the design and implementation of the proposed EdgeToll system with preliminary experiments.

A. *Test-bed Specifications*

Jiangxing edges used in our test-bed are Acorn RISC Machine architecture (ARM) computers with 8 GB RAM and Intel i5-7300 CPU. The edge is also equipped with a TP-LINK WDR5620 wireless access point, which adopts IEEE 802.11g/b standard with 1200 Mbps data rate and 2.4/5 GHz radio frequency.

[2]https://www.ethereum.org/
[3]https://truffleframework.com/
[4]https://www.rinkeby.io/
[5]https://github.com/ethereum/solidity
[6]https://github.com/ethereum/web3.py
[7]https://www.python.org/
[8]http://www.jiangxingai.com/
[9]https://github.com/awkman/pywifi
[10]https://www.json.org/

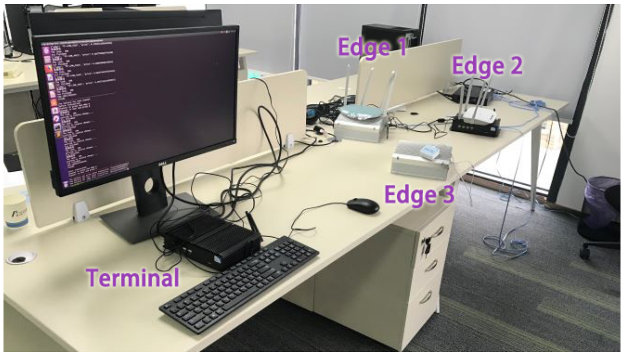

Fig. 4. Demonstration of the Implemented EdgeToll Test-bed

Fig. 4 illustrates a running demonstration of our proposed system, which consists of three edge nodes and one terminal for the end user. All experiments described in following sections are conducted over the test-bed.

B. Experiment Design

Because there are transaction latency and gas fee in Ethereum blockchain, overall service time and the monetary cost should be measured in our experiments. In addition, due to the resource competition among multiple users or multiple edges, the impact of the service requests frequency should be an important factor to be considered as well. Therefore, we design the following tw0 experiments from different perspectives.

- **Benefit of Payment Channel:** the experiment compares the time and cost efficiency with and without the utilization of payment channel technology. Our hypothesis is that with more transactions posted, payment channel will save more time and monetary cost, due to its off chain nature.
- **Cost Minimization:** this experiment is designed to discuss the monetary considerations from the perspective of users. The end users can minimize their costs if there are competitions among multiple edge service providers, given the price for a service unit is dynamic, similar to the spot instance pricing[11] available in cloud computing.

C. Experimental Settings

Here we present the default parameter settings for our following experiments. The default block rate in Rinkeby, approximately one block per 15 seconds, is adopted if no specific settings are imposed. The mobile terminal is a single board computer with Ubuntu 16.04 Linux operating system. By default, we iterate the numbers of users' tasks from 1 to 50 with a step of 5. With proposed system, we assume the users will not close the channel until they complete all of their tasks. Each set of experiments has been repeated for 100 times and their average values were derived as our final results.

[11]https://aws.amazon.com/ec2/spot/pricing/

D. Result Analysis

Fig. 5 and Fig. 6 illustrate the performance comparisons between the system with and without the support of the payment channel. We set up different parameters as depicted in the legends, where *PC* represents using the payment channel, while *WPC* represents the system without using a payment channel. The value of 5s, 10s, and 15s represent the different block intervals used in Fig. 5, while 1 Gwei, 4 Gwei, and 7 Gwei in Fig. 6 represent different gas fee required for posting one transaction to the blockchain.

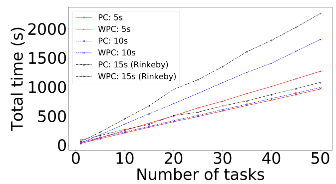

Fig. 5. Total Complete Time

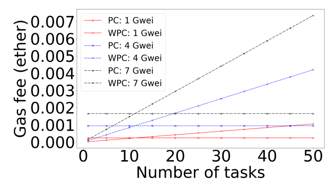

Fig. 6. Transaction Gas Fee

In Fig. 5, we study the impact of users' task numbers on the total completion time, which consists of edge service time and the blockchain transaction delay for the toll payment when applicable. From the results, it is obvious that the total time cost increases linearly as the growth of numbers of users' task. When the total number of users' tasks is small, e.g. 1 task, the total time cost of EdgeToll may be no different to that of systems without payment channel. However, the total waiting time values for conventional approaches, who directly pay tokens through blockchain transactions, are increased at a much higher speed, especially when the block interval is relatively high. For example, the difference of total service time cost between two schemes is 1185 seconds when the block time is set 15 seconds, a common Rinkeby scenario, which means the payment channel can reduce the time cost by more than 110% from *PC*. In fact, the largest overall latency reduction in different block time can be up to 31.8%, 39.6%, 110% in the ratio of *PC*, respectively. Note that, the reduction in Rinkeby is considerably more significant than other shcemes because of the existence of congestion in real world test P2P network, which may indicates the more distinguished performance in authentic production environment.

A similar phenomenon can be observed in Fig. 6, which shows the difference of gas fee the system needs to consume between the two paradigms. One significant feature is that, the gas fee for payment channel based experiments is a constant, no matter how many tasks are posted by the users. This is because all payments for their tasks are sent through the channel, which is a no-cost off-chain process. In fact, the only gas fees they need to pay are the opening and closing transactions in the beginning and the end of their service usage. Things are completely different without the help of payment channel: the total gas fee may increase as the total number of tasks increase. And if the price for the gas increase, the slope will become larger as well. When the number of user' s task is relatively small, e.g. less than 10, the operational cost of WPC is cheaper than PC. But the condition become different as the increasement of task number.For instance, when a user has a heavy workload e.g. 50 tasks and high gas price (gas price = 7 Gwei), the total gas fee without payment channel will be 0.0057 ether nearly 345% larger than that of the proposed EdgeToll system. In fact, even in the low gas price, e.g., gas price = 1 Gwei, the gas fee without payment channel can also be 4.4 times the value of proposed system.

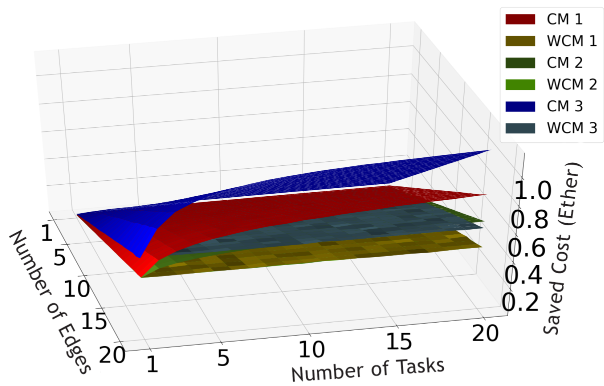

Fig. 7. The impact of task number and number of edges on the saved cost

Fig. 7 shows the result of user cost minimization. In the figure, *CM* represents the cases using user cost minimization algorithms in the proxy, while *WCM* represents the scenarios that the end users randomly select one nearby edge to post their requests. Regarding the dynamic pricing data proposed by the edges in our experiment, we are not able to find corresponding data set for a trace-drive simulation. However, we believe the spot instance price from Amazon Web Service (AWS) can be a reference for us, since they are intrinsically the same mechanism: unit prices are subject to the available resources can be provided. Therefore, we choose a number of random functions to generate dynamic prices for edge nodes, while the mean values of the normal random distribution function can be attained from observing the mean of price history in amazon web service, Linux/Unix d2.xlarge products. In Fig. 7, different schemes are corresponding to different random function. The numeric value *1* indicates a normal distribution with mean = 0.207 and standard deviation = 0.01, the value of *2* means another normal distribution with mean = 0.207 and standard deviation = 0.005, and the value *3* implies a uniform distribution with interval = [0.17, 0.23]. As shown in the figure, the system can bring remarkable benefits to the user. When the price is relatively stable, for example, when the standard deviation is 0.005, the improvement of the system is relatively insignificant. However, when the price vacillates in a uniform random function, the overall saved cost for scenarios with number or tasks = 20 and number of edges = 20 is around 1.14 ether, nearly 93.7% reduction in comparison to a traditional system with 0.59 ether.

VII. Conclusion

An trustworthy and efficient toll collection system is the key to motivate the heterogeneous edge platforms to share their vacant resource from a commercial point of view. In this work, we design and implement EdgeToll, a blockchain-based system, to fill the blank in this area. By leveraging the payment channel technique, we provide a low-latency and cost-efficient solution for a decentralized, transparent and auditable toll collection. We believe that the deployment of EdgeToll will contribute to the public popularization of edges, which can reduce the computational pressure in cloud service and accelerate the future of the Internet of Things (IoT).

Acknowledgment

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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,

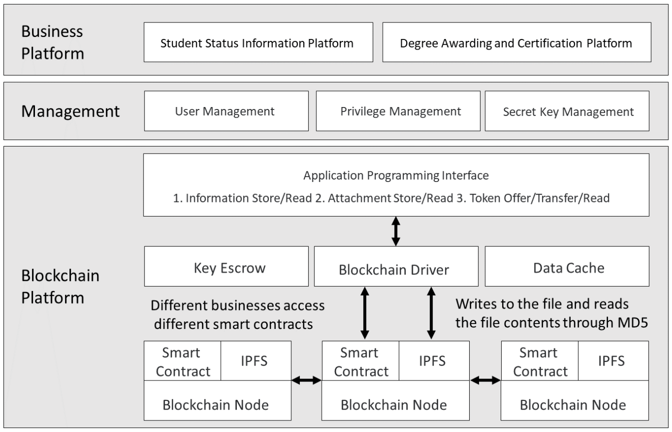

Fig. 1. Framework for EduBloud System

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.

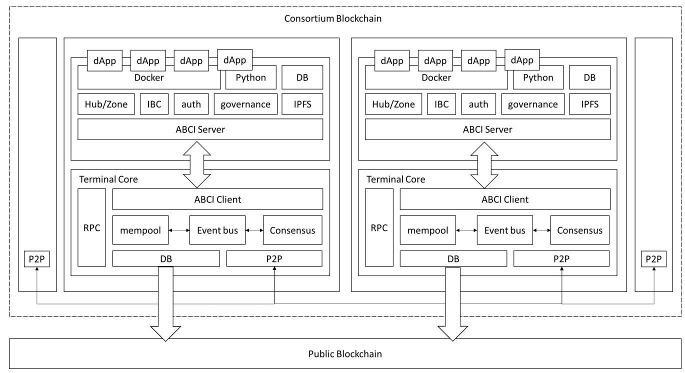

Fig. 2. Architecture for EduBloud System

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	$1\sim2$	12	<4.5
TPS	>300	<200	$15\sim25$	143
Privacy	high	mid	low	high
Tamper Resistance	low	mid	high	high
Failure Rate	high	mid	extremely low	low

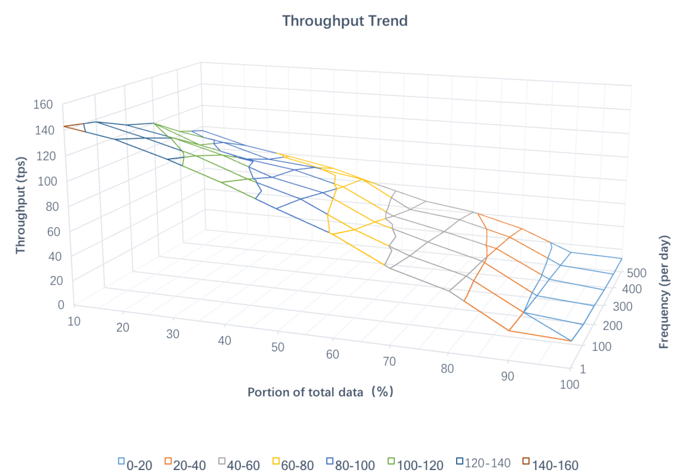

Fig. 3. Throughput

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.

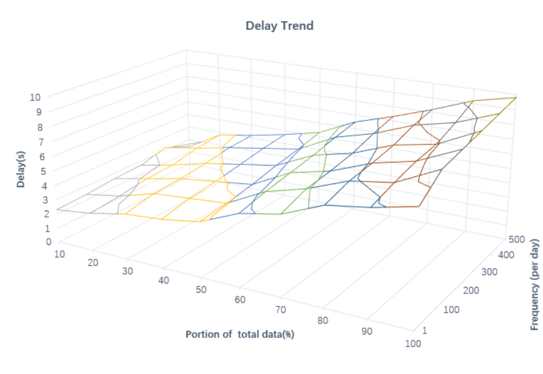

Fig. 4. Delay

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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