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A Survey of Using Blockchain to Build a Decentralized and Trustless Marketplace for Brokered IoT Data Trading

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Abstract: As the data market becomes ubiquitous, it is necessary to study the data streams generated by Internet of Things (IoT) devices. For example, nowadays, security problems are crucial to the process of data transaction. Due to the decentralization of blockchain and difficult data tampering, blockchain can well solve the security problems in data transaction. However, the transaction efficiency of blockchain can hardly meet the current market due to latency and other problems. This article mainly reviews existing research on blockchain and IoT data and put forward possible solutions for dealing with some of the current problems. The present study is mainly divided into three parts, including the classification of research problems, research methods, and the classification of experiments. The main research questions are about insufficient functionality and poor performance on the Internet of Things and data markets. In addition to the discussion on whether to use blockchain, this article also proposes some feasible research directions for future research.

Keywords: blockchain, IoT, data marketplace, Ethereum

1. Introduction

Flow from data on IoT devices and on the market is increasingly seen as tradable assets, which is valuable to device owners and has resale value. Although various dedicated data markets are emerging, whose value is relatively limited compared with traditional static data markets. Unlike static data, these data streams lose value if they are not consumed near real time, and the data transfer and transmission may not be monitored by reliable third-party intermediaries. On the other hand, a data exchange architecture based on a message broker system allows a single data flow to be delivered to multiple parties, which can be very efficient because the data owner can resell his data flow multiple times in real time. While the existing information infrastructure can support large-scale markets, there are inevitably issues of mutual trust among participants. In addition, the transient nature of data flow necessitates efficient and automated mechanisms for the creation of legally binding trade agreements such as payment arrangements, as well as enforcement of those protocols during the data transmission process. Therefore, the application of blockbusting these aspects is of great meaning.

First, this article classifies previous studies in the field of the Internet of Things and blockchain. By reading and analyzing the references, we found some taxonomic points for data available in the market, such as IoT and financial data. Based on these considerations, this article divides them into

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different research priorities, and then analyzes the research methods, such as Redesign and Improving. At the same time, it can be seen that some of these methods apply blockchain technologies to deal with poor security, while some methods can improve and study the existing problems by using new game models or adding a new intermediary platform in the process of data interaction.

Then we compare the experiments and results of these studies and summarize the formulas of these literature experiments. We classify evaluation measures and system parameters of these studies. It can be seen from Table 3 that most research compares the cube settlement costs, profits, price and cube settlement operations, prices, and distributed deployment.

In the end, we can find some special points through summarized questions and research methods. For example, in the current data trading market, third-party intermediaries of data exchange cannot provide sufficient trust, which may prevent honest users from submitting comments. We can implement a prototype using Ethereum and smart contract, and visually demonstrate its transparent capabilities; and then we can apply POW and use price to motivate the delivery rate of data.

This article is divided into six parts. Section II introduces classification of the research objects: a decentralized, trustless marketplace for brokered IoT data trading using blockchain. Section III identifies different methodologies of research. Section IV gives comparative analyses of experiments from existing literature. Section V discusses research opportunities for future studies and Section VI makes a conclusion.

2. Classification of Research Objects

Table 1: Different research objects.

Data type	**User expectation**	
	Function Enhancement	**Performance Improvement**
Financial data	I. [1][2]	II. [3][4]
IoT data	III. [5][6][7][8][9]	IV. [10][11]

2.1. Criteria

In recent years, although blockchain has made great progress on the Internet of Things network and messaging infrastructure, it leads to many problems between participants requiring to be solved. Blockchain can well solve the security problems on the Internet of Things, but the mechanism of blockchain cannot meet the current Internet market. At present, the transient nature of flows requires effective automation mechanisms for the establishment of legally binding trade agreements such as payment arrangements. Based on the current problems of efficiency and lack of trust, we use two independent and different criteria to classify these research objects:

User Expectation. There are two types here: Function Enhancement or Performance Improvement. As the future work of the market and ongoing work, scalability with the growth of the number of participants and transaction confirmation time in the blockchain network and how well design reputation models guarantee the time reduction of high reputation participants. Therefore, this is an issue of low efficiency that we need to impose on people, and the efficiency issue is an essential performance issue. In the process of data transaction on the Internet of things, third-party intermediaries are required to supervise. However, the security of a third-party intermediary itself is an important issue, so the decentralization of blockchain is very meaningful. We think that the trust issue is actually a structural flaw on the Internet of Things. Therefore, we believe that this function needs to be improved.

Data Type. Most of the current data is almost economic, so how to ensure data security and the transaction efficiency of data trading is crucial to the current market. Before the appearance of reasonable ways to solve these text questions, we must divide the data types well. There are two main types, IoT data and financial data, from the perspective of research objects. The existing solutions are to improve the IoT data structure and change the marketplace data environment; and such classification is helpful to divide the research points.

2.2. Classification

According to the standard, all types in the classification are listed in the chart above.

Type I. This type is the financial data problem that requires enhancement in function. For example, during the data transaction process, problems such as the data access delay, the distrust in the data sharing, and the lack of data can lead to the inefficiency of the current credit scoring process and significantly reduce the enthusiasm of the data transaction.

Type II. This type is the financial data problem that requires performance improvement. For example, as the current development of IT brings about innovation in the technology and business fields, there have emerged new business models for data exchange. The question of how to make the data supply profitable is related to both entrepreneurs and academic research. Nonetheless, the pricing mechanisms are complex and the willingness to pay on the buyer side is generally low, which hinder the successful allocation of data.

Type III. This type is the IoT data problem that requires enhancement in function. For example, with billions of devices connected, centralized governance would be an expensive option. Even more critically, it comprises the center of compromise, hacking, failure, and distrust. Thus, automating the monetization of IoT data collected in a well automated, scalable, secure, and trusted way becomes necessary.

Type IV. This type is the IoT data problem that requires performance improvement. For example, current systems often fail to keep raters anonymous, which may prevent sincere users from commenting because they worry that the rater may retaliate. While a number of privacy-preserving reputation systems have emerged, we noted that none is truly simultaneously unreliable, decentralized, and fit for usage in the real-world.

2.3. Explanation of Different Types

Function Enhancement & Financial Data. References [1] and [2] belong to Type I. According to reference [1], the current data-access latency hinders innovation in the field of data-sharing; and problems such as the distrust in the process of data-sharing, and the lack of data all lead to the inefficiency of the current credit-scoring process. In [2], existing market platforms are usually designed for trading discrete data packets. However, these available markets do not support real-time data. While data exchange service platforms and Internet of Things platforms allow the sharing of real-time or near-real-time data, they have no market functions, such as sales, marketing, purchase, and payment data.

Performance Improvement & Financial Data. References [3] and [4] belong to Type II. In [3], the goal is to find and contact the owner of the device that provides the data he needs. If the process is completed by one person, it will last for a long time. But the cost will rise if there are more people needed. In [4], the development of IT brought innovation in technology and business, which led to the emergence of new business models for data exchange. Nonetheless, complex pricing mechanisms and low buyers' willingness to pay hinder the successful distribution of data.

Function Enhancement &IoT Data. References [6, 7, 8,5], and [9] belong to Type III. In [6], billions of connected devices would be an expensive option, including intermediary fees and many other fees. More importantly, there are also the security issues in the data trading process. We need to automate the monetization of the collected IoT data in a highly trusted, secure, scalable, and

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automated way. In [7], a centralized infrastructure cannot provide sufficient trust as a third-party intermediary for data exchange. Therefore, as few institutions and individuals are willing to share their IoT of Things data sets in this hard-to-trust environment, and there is no sufficient mechanism to fully protect the data security of both sides of the transaction, most platforms cannot meet the complex need. In [8], user identities are often exposed due to existing system vulnerabilities, which may prevent users from honestly submitting comments due to the fear of retaliation by their raters. While a number of privacy-preserving reputation systems have emerged, we noted that none of them is truly scattered, unreliable, or fit for usage in the real-world, with e-commerce applications being a very good example. Meanwhile, scoring mechanisms are gradually becoming a device. In [5], the development of the Internet of Things faces many challenges, especially data management. In addition, the Internet of Things systems and services are relatively special, and the traditional data management methods can become tricky, which call for new solutions. In [9], considering the lack of perfect system and regulations for data trading and the lack of supervision by the corresponding departments and organizations, the researchers believe that such a market should not be owned by anybody. Instead, it should fairly and transparently self-implement a set of well-defined governance rules.

Performance Improvement &IoT data. References [10] and [11] belong to Type IV. In [10], on the one hand, recent technology trends such as Industry 4.0 and smart agriculture have driven the next generation of services, forcing IoT manufacturers to develop new related skills. On the other hand, there are a lot of AI and ML startups trying to create insights with just a small amount of data. Based on [11], they focused on an important issue, namely, the economics of the Internet of Things, which can exert a great impact on the success of the Internet of Things applications due to the current geometric expansion of data transaction volume.

3. Classification of Research Methods

Table 2: Different research methods.

Whether to use Blockchain technology	**User scheme**	
	Improvement	**Redesign**
Yes	I. [1]	II. [10][5][6][9][8]
No	III. [3][4][1]	IV. [2] [11]

3.1. Criteria

It can be seen that these ways have been divided into using blockchain technology and without using blockchain technology. The use of blockchain technology and smart contracts will incur transaction data exchange cost, but we can avoid data transactions with untrusted third parties. The approach suggested centers around the concept that every user will report to a Smart Contract on a regular basis about data received from and sent to other users; the Contract would subsequently employ those reports to settle disputes. While many articles do not involve blockchain, these studies can improve the structure by building a new framework, a new platform or using a new technology. According to current the situation we presented above, two independent and different criteria would be used to divide research objects into different types.

In the following, two different and independent criteria are in place for categorizing research objects:

Whether to use the Blockchain: There are two types here, that is, yes or no. Against the backdrop we mentioned above, some studies have improved current structure through the use of blockchain technology. For example, by using prototype implementation of the marketplace model on a private Ethereum network, we can experimentally evaluate the cost/risk trade-offs offered by setting checkpoint frequency, and take advantage of potential external mechanisms for establishing trust among users if they are available. Some studies recommend the application of SDP in IoT so as to motivate sensor owners with price to contribute their data to IoT services, thereby improving service quality and generating higher revenue by selling IoT services to users.

User Scheme: There are two kinds of projects here: improvement or new designs. For example, if a house is unlivable due to problems, the house owner may choose to restore and improve the house or directly build a new house. Therefore, the improvement scheme is actually improving the house, while the scheme of new designs is equal to building a new house. The two types of projects are presented in the following.

3.2. Classification

According to the standard of classification mentioned, all types in the classification are presented in the chart above.

Type I: This type uses the blockchain technology to improve the existing problems. For example, SDP is currently applied to the Internet of Things in order to use price to motivate contribution of data for IoT services from owners of sensors, thereby enhancing service quality.

Type II: This type is using the blockchain technology to build new solutions. For example, we propose the implementation, architecture, and system design of a blockchain-based solution that uses Smart Contracts of the Ethereum to monetize IoT data in a way that does not involve mediation.

Type III: This type is not using the blockchain technology to improve the existing problems. Instead, the use of middleware architecture connecting the appropriate devices and the application or an emerging data market classification framework can also shorten the time of data exchange and reduce the cost of this process.

Type IV: This type is not using the blockchain technology to build new solutions. For example, we can propose a new market design or a game-theoretic model to solve the existing problems.

3.3. Explanation of Different Types

Improvement & Using Blockchain. Reference [1] belongs to Type I, which proposed the application of SDP on the IoT in order to leverage prices to motivate sensor owners to contribute their data to IoT services, thus improving data transactions efficiently and generating higher revenue.

Redesign & Using Blockchain. References [10], [6], [7], and [9] belong to Type II. In [10], they aimed to gain an insight into how such solutions are built using the blockchain technology, and how to develop mechanisms and governance guidelines for such a system. In [6], they propose the implementation, architecture, as well as the system design of a solution that is based on blockchain. Since the smart contract of Ethereum is decentralized, we can monetize IoT data in a way that does not involve mediation. In [7], they provided the detailed design of the architecture of the above solution and its main trust components, which implemented a prototype using Ethereum blockchain and smart contract and visually demonstrated its auditable, transparent, and decentralized capabilities. As for [9], they leveraged the emerging blockchain technology to construct an open, transparent, credible, and decentralized architecture in addition to the widely adopted proxy data infrastructure of IoT, which well protected the security of data transactions for IoT traffic measurement and contract compliance.

Improvement & Not Using Blockchain. References [3], [4], and [1] belong to Type III. In [3], they proposed a middleware architecture that connects appropriate devices and applications. It is

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based on the negotiation between the device and the application, according to the terms of data use. As for [4], they provided a unique definition of the data market and a classification framework that can well provide the structure to the emerging data market research areas. This framework can rationally utilize resources to increase the payment willingness of buyers by increasing the transaction efficiency. In [1], they advocated developing a trust data labeling space for credit scores so that such marking techniques could be used in future credit scoring ecosystem implementation to increase users' enthusiasm for data exchange.

Redesign & Not Using Blockchain. References [2] and [11] belong to Type IV. In [2], aiming at encouraging data owners of all kinds of backgrounds to become regular community contributors of data, they presented a new market design that addressed the ability to process real-time human perception data, and refined the mechanisms of delivery. In [11], they proposed a game-theory model on investigating competing prices over the Internet of Things perception services. Through these price processes and the direction of the data transaction volume, we can find out many problems that we didn't care about before.

4. Analyses of experiments

In the following paragraphs, parameters of the system and the evaluation metric will be identified, as presented in the chart below. We can observe that many existing studies utilize cube settlement cost, profit, price and cube settlement operations, price, distributed deploying

Table 3: Various parameters & metric.

Parameter	Metric			
	Cube settlement cost	Profit	Price	Others
Cube settlement operations	[9]			
Price		[11] [5]	[11][5]	[11]
Distributed deploying				[2]
Others	[9]		[9]	[2]

4.1. Metric of Evaluation

Cube settlement cost refers to the total cost of performing a fixed amount of natural gas transmission data for 1 or 5 cube settlement operations. In fact, the cost of performing a cube settlement operation covering 2,000 data has decreased from 1.26e-7 ether ($2.77e-5) to $2.8e-6 ether ($6.16e-4). In contrast, the cost of 5 cubic settlements for 2000 data has decreased from 3.15e-7 ether (6.93e-5) to 7e-6 ether (1.54e-3). It can be seen that the more amount of data transmitted, the less impact each individual data has on the transaction cost.

Price means that, given the IoT services above, we hope to research competitions amongst the pricing for sensing information. In terms of the alternative case, the user purchases sensing information through only one of the devices. Utility of this user purchasing from services is calculated as:

$$U(s) = vPd(s) - Pf(s) - p(s)$$

in which v represents weight of the detection probability relative to the price and false alarm probability. The weight is random in the user population based on a certain distribution, e.g., uniform. When utility (>0) reaches its maximum, a service provider's demand for sensing information would be produced by the user. This demand is represented by Ds(p), where $p = (P_1, \ldots, Ps)$ include pricings of all services.

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When it comes to complementary cases, a user would purchase sensing information from multiple different service providers; and the price is indicated through S. Utility of this user is calculated as:

$$U(s) = vPd\ (s) - Pf\ (s) - \sum_{s\in S} p(s)$$

in which P f(S) and Pd(S) represent the probabilities of false alarm and the detection of a specific fusion. Similarly, when utility is above zero, the demand would be general.

As for profit, we suppose that the quality of service would range from 0 to1. In general, IoT service's quality is inclined to be better if more sensing data is present, which would gain users more out of the service. For instance, simulated road information on traffic tends to be more truthful when the number of drivers submitting driving statuses increase.$Q_{K(s)}\theta_{j,k}$is essentially a user's price for reservation, and if utility comes out positive, this service will then gain a subscriber. Profit of the provider k can be calculated as

$$F_k = P_{fee}^{(k)} \sum_{j=1}^{J} 1_{U_{usr}(j,k)>0} - P_{buy}^{(k)} s\left(P_{buy}^{(k)}\right)$$

Other metric**s** include latency, coefficient correlation and demand. For example, when prices differ, 1 and 2 are demands of alternative services. Cases of high, medium, and low price are all considered for service 1, i.e., 0.11, 0.51, and 0.91, which uncovers some interesting findings about demand. First, regarding alternative services, users' utility of purchasing one service will decline if that service becomes more expensive. As a result, users will evaluate the utility gained from substitute service providers and shift to whichever that generates utility the best. Therefore, price rising of a service will cause its demand to drop, while those of other services will grow.

4.2. System Parameters

Data transfer rate represents overall minimum data price through modifying the volume of data transferred as well as how often cubes clearance operate.

Price represents all kinds of cost. For example, three segments are included in the price of service 2. At the first segment, the demand gradually rises, where service 2 becomes so high that some users receive negative utility and break away from obtaining information through any service. At the second segment, the demand rises significantly, in which a number of users discover buying information with service 1 would produce a better utility rate, and this leads service 1 to be more demanded as well. At the third segment, service 2 becomes so expensive, at which point every user would prefer to purchase information through service 1. As a result, demand of service 2 will be left zero.

Distributed deploying represents consumer's and sensor's data which based on the data log from the marketplace APIS and data cost by provider (i.e., \$5/1GB for text and \$2/hour/stream for video streaming). Digital bills will be generated by the marketplace when consumers would like to go through their usage, and they can adjust their plans, subscribe to or unsubscribe from various streams of data according to the bills.

There are also some other parameters, such as latency and data transfer date.

4.3. Experimental Comparison

In reference [6], the author compared experimental analysis by integrating APIS with consumer's applications and sensors. APIS would analyze the data quality whenever they receive or deliver a data package and would subsequently send the marketplace the report.

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In reference [5], the authors compared how providers encourage the supply of high-quality sensing data by individually amending each sensor's purchasing price. More specifically, data quality can be optimized according to the collecting, processing, and transmitting of data for their resource usages as well as the purchasing price. For instance, a sensor such as a camera can provide better video quality at the expense of greater bandwidth usage and consumption of energy, which would only happen when the purchasing price is high enough. Developing joint performance optimization and pricing models will be beneficial.

In reference [11], the author compared the complementary services. It should be noted that the demands of all services are equal since users show indifference toward prices. Unlike the case of substitute services, because users prefer to obtain information from different kinds of services, lowering the charge of one kind would also cause demands for both of the complementary services to decrease. Similarly, users will purchase less of both if either one is costly. Furthermore, it is discovered that demand for the OR fusion rule reduces at a slower rate than that of the AND fusion rule; and the AND fusion rule's corresponding best response is more modest. This is because degradation caused by greater probability of false alarm is not significant as enhancement rooted in elevated detection probability, based on the OR fusion rule. In addition, complementary services' prices at the Nash equilibrium surpass prices of the substitute services, which result in more profits, and intuition can be accounted for this. Since with regards to sustainability, the severe competition among various services urges them to lower prices in order to achieve maximum revenue. On the contrary, with complement, competition becomes less intense and it does not require services to decrease their prices as much when there is complement.

In reference [9], the authors compared the analysis above for the purpose of identifying the feasibility to establish a transparent, open, and decentralized accounting infrastructure. Building a marketplace in which data prices can evolve to fairly depend on supply, demand, and quality would be helpful. As for minimizing the mutual costs of maintaining an infrastructure as such, it showed how the absence of real-time requests on operations of settlement can be wielded to manipulate gas prices at the expense of a cheaper transaction. Moreover, with fewer times of settlement transaction, they revealed how scalability was granted with cubes. Nonetheless, because of the considerable number of purpose Smart Contracts deployed at the moment (raising up the price of Ether more than 20 times over the past year), we are aware that the estimated infrastructure costs are tied to the current inflation in the Ether value. As they intend to conduct similar studies with different implementations of blockchain such as Hyper-edge (hyper-ledger.org), we predict that a renovated Ethereum network devoted to settling contracts with reduced incentive costs for miners will be necessary to a decentralized trading infrastructure. Even keeping different possibilities in mind, we firmly believe that a market described as above will create well-grounded business opportunities for miners due to substantial exchanges of IoT data, even at lower transaction and incentive fees.

5. Discussion & Suggestions

This article explores research methodologies and objects of previous studies and uncovers some exploration points of blockchain. Thus, we present some potential directions for future research:

(1) From the perspective of blockchain structure, building a decentralized, trust-less data trading marketplace needs to use a new technology to improve the current financial data structure. For example, we propose applying DPOS sharing mechanism of blockchain to the Internet of Things so as to reduce the time to generate and validate transactions and improves system efficiency. motivate data contribution from sensor owners to IoT services and stimulate for higher service quality. In addition, a voting system based on SDP is established to solve the problem of incomplete decentralization of DPOS.

(2) From the perspective of data marketplace, the customers require to contact the owner of the equipment that provides the data he needs. The process will last for a long time and will cost a lot of money. We can use a middleware architecture that connects appropriate devices and applications to address cost issues due to poor performance.

(3) From the perspective of IoT trading situation, the problem of efficiency needs to be solved. We can motivate sensor owners with prices in order for them to contribute data to the IoT devices, which would make users purchasing IoT services enhance the quality of service and produce greater revenue.

(4) Problems such as data access delays of the current data marketplace, mistrust in data sharing, and lack of data all lead to the inefficiencies of the current credit scoring process during use. We can develop a trust data marking space for credit scoring, which can help enhance the current credit scoring ecosystem.

(5) The development of blockchain has brought innovations in the technology and business fields, contributing to the emergence of new business models for data exchange. Considering that problems of low benefits and high cost prevent the successful allocation of data, thanks to the Merkle tree structure created by the block chain technology, we can use the block chain to save storage space and thus reduce the cost., which can provide structure for emerging areas of data market research.

(6) From the perspective of IoT function and structure, there is a lack of a platform that can share data and motivate owners to share data. Therefore, it is necessary to build a truly trust structure, and anonymous reputation system for e-commerce applications to allow customers to submit ratings and text comments, we propose applying SDP to the Internet of Things so as to achieve this goal.

6. Conclusions

Previous analyses show that it is very difficult to establish a data trading market in a trusted environment. Besides, there exist problems needed to be resolved in this process, including data delay rate, cost, efficiency and other aspects. While the above analysis provides some methods to change the current situation, such as the use of blockchain to achieve a transparent, low-cost prototype, the use of SDP technology to motivate data providers, we still need a technology to improve the current data structure, or establish a new data market in the future due to the increasing number of participants in the blockchain network and the increase of transaction confirmation time.

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