Research on DAG Based Consensus Mechanism for Adjustable Load Metering Data

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Abstract. The distributed ledger technology of blockchain can provide an efficient solution for the trustworthy problem of adjustable load metering data. However, due to the issues caused by nodal constrained resource of computation and storage, high concurrent transactions, and ledger data expansion with elapsed time, etc., it faces non-trivial challenges to design a consensus mechanism for second-level transaction data. This paper presents a shard-based DAG blockchain architecture for large-scale and distributed internet of things scenarios, where each device is a node of the network. These devices construct a multi-hop network, and by using the shard technology, some neighboring nodes belong to the same shard. The preference relationship between transactions is generated based on the shard-based DAG blockchain, and a scalable high throughput block consensus is designed such that using parallel treatment of transactions the throughput of blockchain can be significantly improved. Finally, to improve the limited computation and storage capability, we use container edge service engine in system design.

Keywords: Container Edge Service · Adjustable Load Metering Data · DAG · Blockchain

1 Introduction

With the deepening of electricity market, it is necessary to enhance mutual trust among power dispatching centers, power trading centers and market members. Block chain technology has the characteristics of decentralization, difficult to tamper with, traceability, openness and transparency, collective maintenance and programmability. It has broad application prospects in digital payment, trusted data management, information security and other aspects, and has attracted wide attention from academia and industry in recent years. It provides a new trust model under the open network, which adopts "autonomous governance and autonomous organization", so that participants can achieve mutual trust under the condition of decentralization. So, with the continuous improvement of load

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terminal side device level, the application of block chain technology in source-network load storage market transactions can realize the sharing and mutual trust of transaction data, traceability and tamper-proof, which is an important tool to enhance mutual trust and information security in market transactions, and has an increasingly wide application prospect in power system. Especially, the distributed account book is used to record the adjustable load metering data, and the reliable data storage and electricity fee settlement vouchers are realized in a trustless way, which is helpful to enhance the mutual trust in the source-network load storage transaction behavior.

Decentralization, security and scalability are the "impossible triangle" in blockchain. Traditional blockchain values decentralization and security at the cost of poor scalability, which is mainly manifested in a serious lack of throughput. Take Bitcoin as an example [1]. Because of the strict limitation of the fast time and the need for six block confirmations for each transaction, each Bitcoin transaction takes at least an hour to be confirmed, with more than 150,000 transactions queuing for confirmation at its peak. Therefore, the high latency of confirmation processing makes the processing rate (TPS) of Bitcoin only 5–7 times per second [2], and the TPS of Ethereum is 30–40 times per second, which is far less than the mainstream payment tools such as Visa and Alipay, of which the peak processing capacity of Visa is 60,000 unit per second [3], Alipay's peak processing capacity is as high as 85 thousand and 900 pens per second.

The scalability bottleneck of traditional blockchain is mainly attributed to its consensus mechanism and storage structure. Whether it is the workload proof mechanism or the rights and interests proof mechanism, it essentially requires the whole network nodes to participate in the accounting right competition to reach a consensus on each transaction in the system, which seriously limits the throughput of the block chain system. At the same time, Blockchain uses a chained serial structure to store blocks, only one block can be stored in each round, otherwise there will be a fork, and the capacity of each block is very limited, which makes it difficult to support high-concurrency application scenarios. On-chain expansion technology often cures the symptoms but not the root cause, and is prone to frequent bifurcation and increase the risk of double-flower attacks, thus affecting the security and stability of the system. The off-chain expansion scheme cannot use Bitcoin during the channel survival period, and only collects the data of both sides of the transaction, which may destroy the decentralization and tamper-proof characteristics.

In this context, block chain technology based on Directed Acyclic Graph (DAG) is on the stage. DAG block chain replaces the chain serial structure of traditional block chain with tree or mesh structure, supports multi-node parallel write operation, effectively avoids the serial write limitation of chain structure, and greatly improves the system throughput. It has become a promising research direction to solve the scalability problem of block chain, and has been warmly sought after by academia and industry since it was proposed, and many innovative projects and DApps based on DAG have emerged. Unlike traditional block chains, DAG distributed account books can use blocks or transactions as basic storage units. And the base unit (block or transaction) of each ledger may reference one or more predecessor units, or may be simultaneously referenced by one or more successor units. According to the different ways of data organization in the DAG ledger, two different types of distributed ledger technologies are derived: block-based DAG (BDAG) and transaction-based DAG (TDAG). TDAG allows users of the whole network to operate the ledger. BDAG only opens the operation authority to miners, TDAG can use network resources in real time and support high concurrency, while BDAG only uses network resources after the block is generated.

The distributed ledger of adjustable load metering data with friendly source-network load storage needs to reach a consensus on second-level time particles, and supports high-concurrency data transactions of massive nodes in the Internet of Things environment. At the same time, the distributed ledger of adjustable load metering data is mainly applied to edge devices with weak networking capacity and limited computing resources. Also, from a security standpoint, the number of lightweight clients should not be too large. This requires the use of containerized edge computing service engine to enhance the networking and computing capabilities of edge devices, so that adjustable load metering data can be quickly linked on the device side, while ensuring data security. Therefore, combined with the practical application scenarios of adjustable load metering data, in this paper, we will design an improved TDAG distributed ledger structure, which is suitable for the distributed Internet of Things scenario and can adjust the load metering data, and is able to effectively prevent nodes from doing evil and attacking and quickly reach a consensus among nodes.

2 Related Work

DAG is a new generation of blockchain technology for the future. From the perspective of topology model, it has evolved from single chain to tree and mesh, from block granularity to transaction granularity, and from single point transition to concurrent writing, realizing an innovation of blockchain technology from capacity to speed. In the following, according to the data organization structure of the DAG, BDAG technology based on block and TDAG technology based on transaction are introduced respectively, and then the application of block chain technology in power system is introduced.

2.1 Block-Based BDAG Technology

In 2015, Sompolinsky et al. [4] introduced DAG into blockchain technology for the first time, and proposed the Ghost (Greedy heavier-observed sub-tree) consensus algorithm based on DAG. Ghost evolves the single-chain structure of the traditional block chain into a DAG tree structure, and selects the main chain nodes according to the principle of maximum weight subtree. It allows multiple blocks to be packed in parallel, and can solve the expansion problem of transaction processing capacity within a certain range. However, the blocks on the non-main chain will be discarded, and the throughput will not increase linearly with the increase of the number of nodes. In the Inclusive [5] consensus protocol proposed by Lewenbegr et al., each block can refer to multiple parent blocks, sort the whole network blocks based on the network backbone, and then eliminate illegal transactions. As a result, legitimate transactions in all blocks will be included in the final distributed ledger.

In the Conflux [6] protocol, each block has a unique parent edge and multiple reference edges. The parent edge is used for the consensus backbone, while the reference edge is used to determine the order in which the blocks appear. These three protocols are BDAG technology based on consensus backbone, and the throughput of Inclusive and Conflux has a linear positive correlation with the number of nodes.

There are also BDAG technologies that do not require a consensus backbone, including Spectre [7], Phantom [8], and Meshcash [9]. Spectre protocol introduces a voting mechanism to solve the ranking problem of conflicting transactions, but it is not scalable because it cannot sort all transactions globally. The Phantom protocol [10] requires honest miner to reference all end-blocks and must broadcast that flood immediately after the block is generated. Using the greedy algorithm, the blocks generated by the honest nodes form a tightly connected set k-cluster (called the blue set), and the other blocks form the red set. Prioritize blocks in k-cluster as a reward for honest behavior. In Meshcash [11], an honest node generates a new chunk through the PoW mechanism and needs to reference all the end chunks in the DAG view. It introduces two mechanisms, namely, the consensus of the rabbit strategy and the consensus of the tortoise strategy, which can support high block rate and throughput.

2.2 Transaction-Based TDAG Technology

In 2015, the DAG-Chain technology [15] proposed by Sergio Demian Lerner realized the DAG distributed ledger based on fine-grained transactions for the first time. At this time, DAG has evolved into a solution that completely abandons the block chain, which can theoretically greatly improve throughput.

DAG-Chain allows each transaction of the user to directly enter the ledger and participate in the transaction sorting of the whole network. In order to prevent DDoS attacks and avoid waste of computing power, users need to do lightweight PoW before sending transactions. Its main contribution is to introduce the confirmation score () to filter double-flower transactions, and also provides an important reference for the subsequent TDAG technology. IOTA [12] inherits the basic idea of DAG-Chain. Its consensus mechanism Tangle assigns its own weight and cumulative weight to each transaction, where the former is proportional to the size of PoW, and the latter is the sum of the weights of direct or indirect successor units, and then uses Monte Carlo Markov chain algorithm to provide reference for each transaction to select parent nodes. However, when the number of network nodes and transactions is small, it is vulnerable to double-flower attacks. So IOTA introduced an “arbiter” to issue checkpoints and trade confirmations on a regular basis. Avalanche [13] designed a series of basic schemes, including Slush, Snowflake and Snowball, and reached a trading consensus through random interaction sampling between nodes and leaderless Byzantine agreement.

Byteball [14] introduces witnesses and main chains in the consensus mechanism, and then realizes the whole network transaction ranking. Each user may select 12 users or corporate entities of repute or good standing to form a witness list, but must refer directly or indirectly to all transactions posted at the same address. Starting from each end unit, tracing back to the creation unit along the edge of the optimal parent node, a main chain from each end unit is obtained, the main chain intersected in the backtracking process is regarded as the main chain of the system, and the node at the intersection is called Stability Point. Then we assign a main chain serial number to each node on the main chain of the system, and assign a serial number to the non-main chain nodes according to the reference situation. When a double-flower transaction exists, the transaction with the smaller serial number in the main chain is considered legal.

Hashgraph [15] packages each transaction as an event, realizes information exchange through rumor spreading protocol, and carries out virtual voting with the help of locally stored Hashgraph to achieve leaderless Byzantine consensus. It can greatly reduce the communication overhead and effectively resist DDoS attacks. Nano [16] maintains a chain of all transactions for each user, Asynchronous updating of the ledger between different chains can be achieved, but because each transaction bifurcates the sending transaction and the receiving transaction, the corresponding node must be online to complete the transaction. Dexon [17] also uses a block lattice structure as a distributed ledger, which contains several parallel chains, each of which has an independent consensus, and the chains confirm each other by referencing fields. And it utilizes these reference relations to realize that sort of the whole network.

3 Improved DAG Distributed Ledger Technology for Adjustable Load Metering Data

In this paper, we propose a fragmentation-based DAG blockchain architecture for large-scale distributed Internet of Things scenarios. Massive logistics network equipment together to build a multi-hop network, if the traditional chain structure is used, all electricity records need to be stored in the block of each node. However, considering the scale of power consumption records, the efficiency of single chain is low, and the fragmentation scheme must be designed. Within a certain period, a certain number of available adjacent nodes form a fragment. These nodes work together to verify their transactions, generate and save a block, then update the fragment, regenerate and save the block. The blocks are sorted by generation time to form a single block chain. Because the shard is continuously updated, in order to effectively retrieve the persistent record of a node, consensus between asynchronous blocks needs to be achieved throughout the network by creating a DAG structure associated with the blocks. As shown in Fig. 1, the load adjustable node devices in the scenario are used as network nodes to jointly construct a multi-hop network, and a certain number of adjacent nodes are divided into the same fragment by using the fragmentation technology.

The DAG blockchain records all available power as transactions on the node. The transaction record refers to the residential ladder electricity price, calculates the electricity price of a month's electricity consumption in the adjustable load node equipment, and sends out the electricity consumption and the calculation result as a transaction, so as to realize the intelligent charging method. A new block is generated according to all power consumption conditions of each month in the same fragment, and the blocks stored in the fragment form a chain structure according to the time sequence.

In order to establish the partial order relationship between transactions, the consensus committee is dynamically formed within the fragment, and the practical Byzantine fault-tolerant algorithm (PBFT) mechanism is used to determine the order of transactions within the fragment and form a block. A certain weight coefficient is given to each block of the fragment, and the main chain sequence is determined according to the size of the coefficient. Each block keeps the electricity consumption and the electricity charge for a period of time (one month). Each slice maintains a single chain, and each time the slice is updated, the nodes will be scattered in each slice. In order to effectively retrieve the persistent records of a node, a connection is established between the newly recorded block and the old recorded block, and a DAG structure related to the block is created, as shown in Fig. 2.

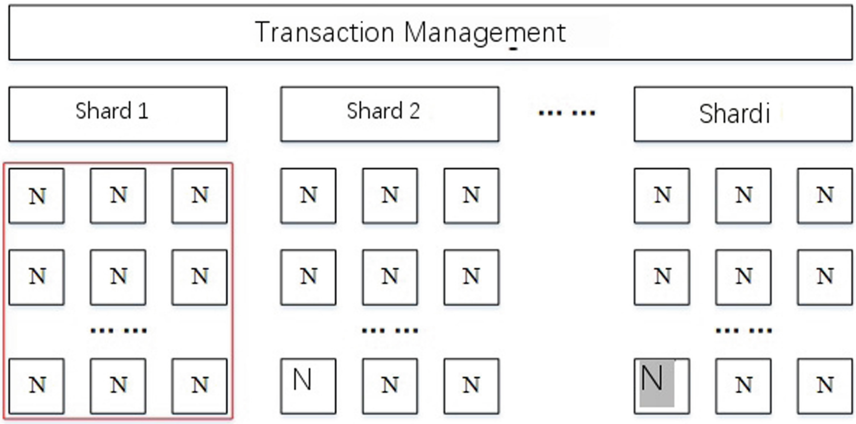

Fig. 1. Blockchain architecture based on fragmentation technology.

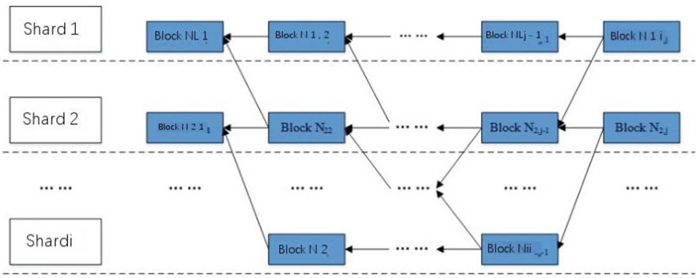

Fig. 2. DAG-based blockchain.

In the block chain based on fragmentation technology, each fragment independently forms a consensus committee and uses the Byzantine Fault Tolerance Algorithm (PBFT) mechanism to generate a block. The details are as follows: The election and update of the members of the consensus committee depend on the random number and the timestamp function. Specifically, suppose there are N nodes, which need to be divided into N pieces. If the number of members of each fragment is K (< N/n), the nodes corresponding to the first n maximum values of the random numbers are respectively allocated to n fragments, the nodes corresponding to the n maximum random numbers from n + 1 to 2 are allocated to n fragments, and so on. The nodes within the shard work together to validate their respective transactions and generate and save a block. Every other cycle, the members of the partition and consensus committee are updated according to the time stamp function and the random number, and the newly generated blocks are saved. Using the Byzantine fault-tolerant algorithm (PBFT) mechanism, the blocks in each fragment are sorted by generation time to form a single block chain.

4 Distribution of Weight Coefficients for Partitioned Blocks

The initialized DAG ledger contains only one creation unit. When a user generates a transaction and broadcasts it to the blockchain system, other users perform transaction verification and consensus according to the DAG graph saved by them.

4.1 Node Punishment and Reward Mechanism

The adjustable load mainly comes from the customer-side load. In the process of load regulation transaction, malicious behaviors such as node evil, malicious competition, attacking the account book and false declaration will lead to invalid transactions. In order to prevent nodes from doing evil as much as possible, the system initializes a credit value CreditVal with 6 points and 10 points for each user. For users who launch attacks such as double-flower trading and DDoS, the system automatically reduces their credit value and deducts 1 point each time. For users with "lazy" behavior, 0.1 points will be deducted each time. As a reward mechanism, the credit value of 0.1 points will be added to the users who discover the double-flower transaction and broadcast it to the whole network in time. A "diligent" node that has not done evil for a period of time (such as a month)., and also increase its credit value appropriately. The higher the user's credit value is, the more reliable the transaction generated or authenticated by the user is, and the transaction generated or authenticated by the user can be preferentially referenced by other transactions.

4.2 Transaction Verification

For each new transaction, certain rules must be followed to verify whether the transaction is valid before forwarding, and the verified transaction will enter the trading pool. For example, to confirm whether the balance of the transaction output party in the predecessor unit after the transaction is negative, it is necessary to query all the transaction records that have been directly or indirectly verified by the transaction output party. And then determine whether the balance is sufficient to pay for the transaction. If the new transaction is not properly validated so that it passes a transaction with a negative balance, it will not be recognized by other transactions.

In order to improve the convergence speed of the DAG ledger, users need to refer to (or verify) n (>1) transactions in the DAG graph as the predecessor unit (or parent node) when sending transactions, and the probability of the "lazy" node being selected as the predecessor unit should be very low, while the "diligent" node should be confirmed as soon as possible. The "lazy" node here means that the node confirms the old transactions that have been verified. Or a lack of careful verification resulting in conflicting transactions (e.g., insufficient balances) being verified. Therefore, this paper requires that these n transactions are all unconfirmed transactions, namely Tip transactions, because there is a possibility of nodes doing evil (such as sending false transaction information), the possibility of Tip transactions in DAG failing to pass verification is greater than that of verified transactions, and false transactions should be identified as soon as possible. The DAG storage space can be simplified, the transaction confirmation efficiency can be improved, and the network communication overhead can be reduced.

4.3 Determination of Transaction Sequence and Main Chain

For each node in the shard u_i the comprehensive weight coefficient is defined as

$$w(u_i) = f(\frac{C(u_i)}{C}, \frac{CreditVal(u_i)}{10}, R)$$

where, $w_1(u_i) \triangleq C(u_i)/C$ represents the ratio of the transaction limit in the unit to the maximum limit of all transactions in the corresponding level set. $w_2(u_i) \triangleq \frac{CreditVal(u_i)}{10}$. To initiate a transaction u_i the user's relative credit value, R is the transaction confirmation ratio, which is the number of Tips that directly or indirectly validate the transaction divided by the total number of Tips, and varies over time. Generally speaking, the larger R is, the more reliable the transaction is. The weighting coefficient is a function of these three, and f can be any normalized function that is positively correlated with these three, such as an average function. So, the weight coefficient is often larger for transactions with high credit value users, large transaction amount or large confirmation ratio. Here we also use the transaction quota as a parameter, because the double-flower transaction is often a large transaction, and the transaction cost is used as a parameter of probability measurement to verify the large transaction as soon as possible. And the weight of each transaction is not based on the cumulative value of the transaction, so that the occurrence of the double-flower transaction can be effectively controlled.

We use the comprehensive weight coefficient to select the parent node, and then dynamically construct the main chain, based on which all transactions are sorted. The main chain construction process starts from the creation unit, and the next node on the main chain (i.e., the parent node) is selected according to the greedy mode based on the weight coefficient. In particular, we first select the transaction with the highest weight coefficient from L (1), the set of all transactions that directly refer to the creation unit, and write it as u_1. If there is a knot (that is, the weight coefficients of multiple transactions are the same), the transaction unit generated by the user with the largest relative credit value is selected. Then, select Direct Reference u_1 as the next node on the main chain, and so on.

After obtaining the main chain, we can assign a main chain sequence number to each transaction on the main chain, and generate a global sorted view to facilitate transaction query. The specific method comprises the following steps of: firstly, setting the serial number of the main chain of the creation unit to be 0, u_1 the sequence number of the main chain is 1, u_1 has a subunit backbone sequence number of 2, and so on. For other transactions in L (H), the serial number is allocated according to the weight coefficient. For example, the transaction with the largest weight coefficient in L (H) except the nodes on the main chain is allocated with the serial number H. 1. The transaction with the minimum weight coefficient is assigned a serial number H. K, where K is the number of elements of L (H). Note that the sequence number here only indicates the order in which the transactions appear in the ledger. For ease of indexing and fast access, the size of the sequence number itself is not important.

5 Containerized Edge Computing Service Enabling TDAG Distributed Ledger

Adjustable load nodes often have weak networking capacity and limited computing resources, so it is difficult to play the role of a full node. The DAG distributed ledger based on transaction is slightly less supportive to lightweight clients than the DAG distributed ledger based on block chain, and there are some security risks. For example, a user's frequent queries of a list of transactions of interest can easily expose relevant address information. Bloom filters can be used to solve some of the problems, but from a security point of view, the number of lightweight clients should not be too large.

Moreover, if the networking ability of the device is weak and the computing resources are limited, it will cause computing and network communication delays such as Hash, which will bring greater security risks. Therefore, we need to enhance the communication and computing capabilities of edge devices through a reasonable device management mechanism with the help of containerized edge computing service engine, so that the adjustable load node can fully meet the needs of the node. To ensure that the adjustable load metering data can be quickly linked on the equipment side, while ensuring the security of the data.

With the help of containerized edge computing service engine, using 4G wireless network and other wired networks to communicate, providing powerful edge computing capabilities, complete security and comprehensive intelligent services, data optimization, real-time response, agile connection and intelligent analysis can be realized on the edge side of the Internet of Things, and the configuration interface is abundant. The acquire data is calculated in real time on that edge side. In addition, with the powerful computing power provided by the edge box, we can build a cloud edge collaboration framework, introduce artificial intelligence technology into DAG distributed ledger, realize the intellectualization of in-chain enhancement and out-of-chain governance, and solve the weaknesses of DAG technology in transaction confirmation and security.

6 Conclusions

In this paper, a transaction-based DAG consensus mechanism for adjustable load metering data is proposed. According to the characteristics of adjustable load measurement data, the partial order relationship between transactions is established by introducing the fragment structure and DAG structure, and the parallel transactions are processed by building a fine-grained transaction sequence relationship, which effectively improves the overall throughput. It can overcome the problem of packaging all transactions into one block in the traditional block chain. In future, we will apply this approach to solve the problems in social networks and mobile computing, etc. [18–31].

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