A Comparison of Distributed Ledger Technologies in IoT: IOTA versus Ethereum

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***Abstract*—There is an increasing interest in adopting distributed ledger technologies (DLTs) to IoT applications that enable secured interaction between IoT devices without third-party involvement. Among recent advanced DLTs, Ethereum blockchain and IOTA Tangle are emerging as promising candidates for various IoT use cases. Both offer various IoT-friendly features such as lightweight crypto, open-source implementations, energy-efficient operations, etc. So far, the two technologies have only been qualitatively evaluated together in the literature. There has not yet been a performance comparison between IOTA and Ethereum in an IoT application. To address the issue, we build an IoT environment that can run both DLTs and compare their performance. We thoroughly investigate the DLTs' three layers (i.e., Consensus, Network, and Storage layers). In the first layer, we evaluate the CPU utilization and number of transaction; in the second one, the DLTs' network performance is compared. Meanwhile, disk and memory usage are derived in the third layer. The results show that IOTA performs better with most performance metrics.**

***Keywords*—IoT, Ethereum, IOTA**

I. Introduction

There has been an increasing interest in integrating the Internet of Things (IoT) and Distributed ledger technology (DLT) [1], [2]. The primary motivation is that the two potentially fulfill each other, although they are very different. IoT can provide connectivities and interoperability between a large number of IoT devices, each of which can sense physical events. The collective sensing data combined with advances in AI-based data processing will promisingly improve various aspects of human lives. However, that massive amount of data has faced several issues, including centralized IoT architecture, lack of security, privacy, and pervasive trustee. DLT is commonly acknowledged as the technological infrastructures and protocols that allow simultaneous explosion, synchronization, and modification of an immutable database in a decentralized manner among multiple entities. DLT, which theoretically handles all the mention issues by design, can be an enabler to provide needed security, privacy, trust for IoT operations.

One of the most widespread data structures of distributed ledgers is the blockchain, which shapes the database into a chain of blocks with transactions involved inside. The blockchain technology, which is initially not designed for IoT, has been popular in public with cryptocurrencies, such as Bitcoin. In the IoT realm, one of the most popular applied blockchains is Ethereum [3], which has significantly improved IoT devices cooperation [4] or IoT scalability [5]. Another emerging DLT that is designed to cope with the systematic challenges imposed by IoT is IOTA. Unlike blockchain, IOTA has a unique data structure called the Tangle constructed by directed acyclic graphs (DAG), which organizes the database into a mutually authenticated net of transactions. IOTA has shown its advantages in enhancing IoT applications' security and privacy [6], [7].

In the literature, there have been few works that addressed the issues. In [8], the authors have qualitatively compared Ethereum and IOTA the difference between Ethereum and IOTA in three use cases. They provide theoretical analysis and comparative process for the comparison. This approach is efficient but less accurate than the practical one since it relies on assumptions. Regarding the practical comparison, the previous work normally selected a single parameter such as the end-to-end latency [9]. Although the latency is among the most important metrics in DLTs [10], the other ones are also worthy of investigating. Hence, such evaluation is not enough to compare the superiority between IOTA and Ethereum. Moreover, the DLTs have not been matured; in fact, they have been rapidly developed. For example, IOTA has recently updated with several fundamental changes. Hence, the previous comparison will likely become outdated.

The objective of this work is to thoroughly analyze and compare the performance of the two DLTs in a similar IoT application. More specifically, we deploy the latest versions of Ethereum and IOTA on the environmental monitoring IoT systems, each consisting of two Raspberry Pi 4 (PRi4) (i.e., IoT devices). The systems have actual sensors to collect Particular Matter (PM) data from surrounding environments. Additionally, we investigate the performance following the three-layer architecture of DLTs (i.e., consensus, network, and storage layer). Within the architecture, the PM data is authenticated in the consensus layer, propagated in the network layer, and stored in the local database in the storage layer. In the consensus layer, we track and compare the variation of CPU utilization and the number of transactions involved in the ledger. In the network layer, we focus on network throughput. In the storage layer, we evaluate the disk and memory space usage occupied during DLT operations. The results show that IOTA performs better with most performance metrics. Moreover, they reveal characteristics of parameters with two DLTs. Furthermore, the evaluation results also provide the varying attributes of CPU and storage.

The remainder of the paper is as follows. Section II presents related works. Section III introduces the DLTs' background. In

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Section IV, we show the comparison methodology. Section V presents the results. Finally, Section VI concludes the paper.

II. Related Work

In [2], [11], the authors comprehensively survey blockchain in various IoT applications. They have pointed out the necessity of decentralizing IoT architecture and discussed the applicability of blockchain. In [1], [12], the surveys related to security issues of IoT blockchain solutions have been provided. They discuss the advantage and disadvantage of the state-of-the-art blockchain solutions for IoT. Among the blockchain technologies, Ethereum with its appealing smart contract is promising. In [13], Ethereum is combined with an ad hoc routing protocol to improve the resilience of IoT networks. In [14], Ethereum is used to manage IoT devices' access control. In [15], the authors provide a deployment of the emergency services in smart home, based on a private Ethereum blockchain with Solidity smart contract. The works in [16], [17] have evaluated the performance of Ethereum in IoT scenarios with and without the cloud.

Regarding the IOTA and its application in IoT, the work in [18] introduces the detailed operations of IOTA, IOTA implementations, and its challenges when applying to IoT. In [6], the authors introduced ae way to secure transferring of IoT sensor data using IOTA. The proposed system realizes secure data transfer by implementing IOTA's Masked Authenticated Messaging (MAM) function. In [7], the authors discuss two IoT applications, which are a smart utility meter system and a smart car transaction system. The work in [19] introduced a micropayment system running on IoT devices. The system adopted IOTA as both DLTs and cryptocurrency. In [7], the authors described in detail the way IOTA enhance the security and privacy of IoT application.

Performance comparison of IOTA and Ethereum has been conducted in several works including [8], [9]. While the former represents the theoretical approach, the latter is for the practical one like ours. As mentioned, the theoretical comparison is normally less accurate since it has to rely on assumptions (of analytical models, traffic patterns, etc.). The previous practical works have not comprehensively compared the two DLTs. More importantly, the up-to-date IOTA (IOTA version 1.5) has not been evaluated in the literature. Different from others, this work investigates IOTA and Ethereum in their latest forms with various performance parameters.

III. Background

DLT includes procedures and protocols to replicate a timestamped and ordered database (i.e., ledger). In operations, a node in the DLT network stores a copy of a shared ledger. The ledger's consistency is always maintained employing hash chaining. When DLT appends new data (i.e., transaction) to the ledger, the nodes must complete the rules defined by a consensus mechanism. Depending on DLT implementations, the detailed processes, protocols, consensus are different.

A. Ethereum

The open-source Ethereum is one of the most popular blockchain platforms featuring smart contracts, which are automatically executed programs pre-submitted to the blockchain. Ethereum is renowned for the functionality of cryptocurrency over a public blockchain network, namely the Mainnet. At the same time, Ethereum also supports private blockchain, which can be edited and deployed to fit in different IoT scenarios. In both public or private Ethereum blockchain, uploaded smart contracts can be triggered by transactions. A submitted transaction from a node will broadcast to all other nodes among the network. Each node maintains a transaction pool (txpool) to keep all pending transactions. A node with the ability to execute the PoW consensus algorithm will select some transactions from txpool to form a block and authenticate them with the output nonce of the PoW algorithm. An authenticated block will be broadcast to other nodes. On receiving the block, nodes need to confirm the correctness of the nonce contained in the block header. If the nonce is validated, the block will be appended to the local blockchain database. When all of the nodes accept the block, they are regarded as reaching a consensus on the new block. Geth is the official Ethereum client written in Golang.

B. IOTA

IOTA is an open-source DLT that aims provides a trust layer for IoT devices. IOTA has a unique data structure called Tangle. The Tangle is constructed by directed acyclic graphs (DAG), which does not have blocks, only transactions different from other DLTs such as Ethereum. Therefore, IOTA only needs to approve a transaction, then makes the high-speed transaction possible. IOTA adopts the PoW mechanism, which allows issuing transactions by approving two or more previous transactions. This approval process is divided into three parts: tip selection, PoW, and broadcast. IOTA's tip selection algorithm determines the two previous transactions to attach the Tangle network. The tips, which are not yet approved transactions, are selected by milestone transactions issued by the coordinator. The coordinator manages the IOTA network to prevent double-spending and transaction conflicts. The PoW is the hash calculation for approving the previous two transactions. Then, the client, who wants to attach the transaction to the Tangle network, does the hash calculation ownself. In Broadcast parts, the transaction sends its own information to the Tangle network. Through these processes, IOTA can issue a new transaction. Nowadays, the IOTA community has been actively developed new features. IOTA Smart Contracts Protocol (ISCP) is one of the notable technologies. ISCP can reduce energy and calculation costs by the DAG architecture. However, ISCP is under development and has not matured yet. Additionally, in May 2021, the IOTA Chrysalis (IOTA version 1.5) has been presented. The up-to-date IOTA protocol has several new functions with the new IOTA API. This work use the IOTA Chrysalis.

IV. Comparison Methodology

A. Three-layer architecture

In a DLT system, there are generally multiple nodes that cooperate to maintain a shared ledger, which contains all historical transactions. Any participant can launch a transaction to initiate or modify the ledger's content. Following the transmission involvement process, we divide a DLT system into three layers as indicated in Fig. 1. When a transaction is

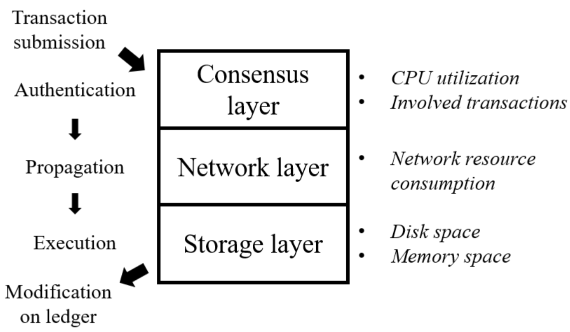


Fig. 1: DLT's three layers

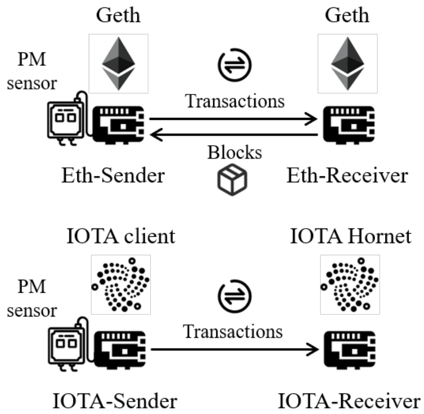


Fig. 2: Implementation

submitted, it needs verification and authentication by the consensus algorithm located in the consensus layer. In Ethereum, one of the most popular consensus algorithms is Proof-of-Work (PoW); the authentication process is mining. IOTA also adopts PoW; however, its implementation is different from the Ethereum one. After authentication, the transaction could then be disseminated to the entire network in different forms (e.g., inside Ethereum blocks or appending to the Tangle in IOTA). The propagation process is in charge of the network infrastructure. Consequently, the broadcast transactions are recorded to the ledgers at the storage layer, where they are finally executed to modify the corresponding items.

B. *Performance metrics*

Considering the functionalities and the resources consumption in each layer, we investigate the following performance metrics (i.e., presented in Fig. 1). We also describe the associated measurement tools.We compose the above utilities in a file as the monitoring tool. It is then integrated with the cron daemon on each device (i.e., in *crontab*), which can execute the monitoring pattern periodically (i.e., every minute).

1) Consensus layer:

CPU utilization: On the consensus layer, DLT collects submitted transactions and executes PoW for the consensus. The PoW execution needs computational power due to the requirement of calculating hash functions. Therefore, it is necessary to monitor the CPU utilization of resource-limited IoT nodes during DLT running. We use a bash script to capture the CPU time statistics from the Linux's `/proc/stat` file and then calculate the CPU utilization.

Number of involved transactions: As a result of the consensus algorithm, transactions are constantly authenticated and disseminated. However, the speed of transaction involvement is restricted by the heavy computational demand. The number of involved transactions becomes an important index for the capacity of DLTs. We collect the number of transactions inside each block with inter-process communication (IPC) for Ethereum. The number of accumulated transactions is logged with a Python script in the IOTA client.

2) Network layer:

Network resource consumption: On the consensus layer, nodes among a distributed ledger network have to frequently exchange current states, propagated transactions, and synchronize peer information through its underlying network. This metric shows how efficiently the DLT uses network bandwidth and the potential number of devices accommodated in the network. Therefore, the metric plays an essential role in understanding the whole blockchain performance. We log and read the accumulated bytes of data transmitted and received from the `/proc/net/dev` file from the Linux system.

3) Storage layer:

Disk space usage: DLTs request nodes keeping the entire historical transactions locally. Those historical information is permanently retained and forms the database of a DLT implementation. Hence it is worthy of investigating the disk usage. Specifically, Ethereum keeps transactions and blocks in a key-value LevelDB [1], while IOTA keeps its database in a column separated PebbleDB. We use the Linux tool named `df` to get the values of disk space usage.

Memory space usage: DLT implementations occupy memory space during executing consensus algorithms for convenient access and temporary storage. Therefore, memory space usage relates to the capacity of achieving functionalities over IoT devices. Moreover, the execution of the JavaScript or Python library also requires memory space for caching. As we observed, Ethereum stores pending transactions and the state tree in the memory, while IOTA only keeps accumulated transactions. The memory usage value can be obtained with the `free` tool.

C. *Ethereum versus IOTA*

In this work, we implement two similar systems using Ethereum and IOTA, as shown in Fig. 2. Each system has two IoT devices with an actual PM sensor. Eth-Sender, Ether-Receiver represents the sender and the receiver in Ethereum blockchain. Both of them have Geth, which is an Ethereum client. Similarly, we have IOTA-Sender and IOTA-Receiver with IOTA clients. We deploy the monitoring tool to the IoT devices. The detailed operation processes of DLTs are presented in Fig. 3.

[1] https://github.com/ethereum/leveldb

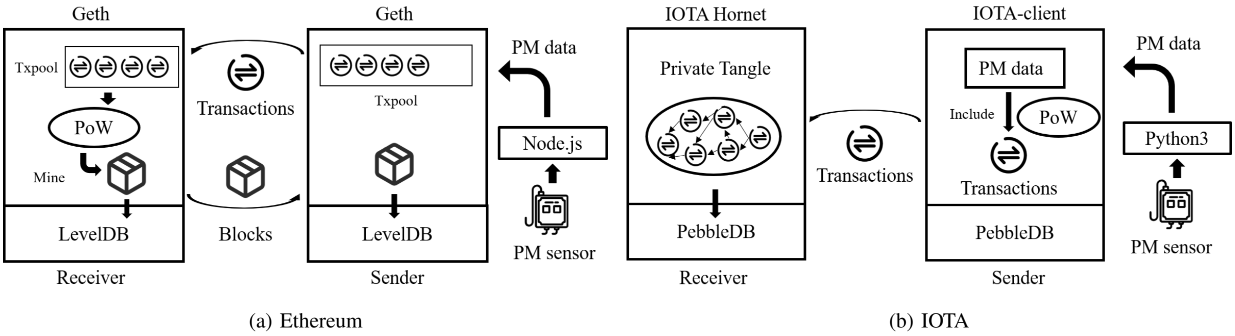


Fig. 3: Operation processes

The Ethereum processes are in Fig. 3a.The PM sensor delivers data to the sender, which will be included in a transaction, inserted into the local txpool, and broadcast later. When the receiver obtains the transaction, it will mine the transaction into a block with the PoW process. A produced block will propagate to the sender. The transactions inside the freshly produced block will be executed and stored in the storage layer, containing the state tree in memory space and permanent historical records in the disk space. Figure 3b shows the IOTA's processes. First, the sender collects the PM data through the `sds011` Python3 package. Next, the sender executes the PoW and includes the PM data in the transaction using IOTA-client software. The transactions are attached to the Private Tangle network build by the receiver using `IOTA hornet`. Finally, the transactions are recorded in the private Tangle, and data are transferred to the Pebble database.

V. Performance Comparison

A. Setup

In our implementation, we use RPi4 as IoT devices and Nova PM Sensor. The IoT devices communicate to each other via an Wi-Fi access point. Table I shows the detailed device configurations. In both systems, we construct the private DLTs on top of the physical connection.

In the Ethereum system, we deploy the Geth clients on both the sender and receiver. We create a custom genesis file to launch the clients in a private blockchain deployment. In the genesis file, we set a proper `difficulty` value to ensure the receiver could finish the PoW calculation in a reasonable time. Then, we upload a smart contract to record the `PM10` and `PM2.5` data. The sender constantly broadcasts transactions containing the PM data collected from the sensor with a Node.js script. In the IOTA system, the sender has an IOTA client with a python library environment that is created by the cargo build function from the `iota.rs`[2] library. On the receiver, we install the IOTA Hornet from `github source` [3]. We then construct a private Tangle by configuring the coordinator who manages the private Tangle in Hornet. In the coordinator setting, we can determine the difficulty of PoW, the configuration of the database, etc. In this evaluation, we use IOTA version 1.5, in which we set the minPoWScore value representing the difficulty of PoW to 100. In the evaluation, we continue to issue transactions in one hour and collect all the monitoring performance parameters of the three layers in the two systems.

[2]https://github.com/iotaledger/iota.rs/tree/dev/bindings/python
[3]https://github.com/gohornet/hornet

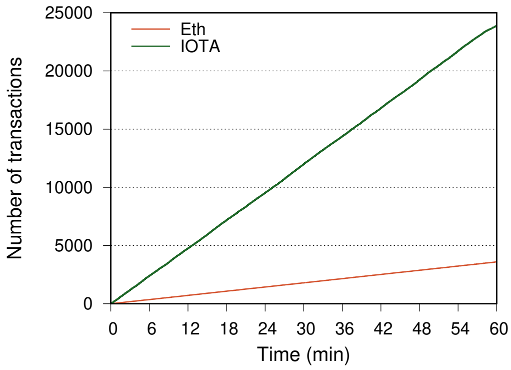


Fig. 4: Number of transactions

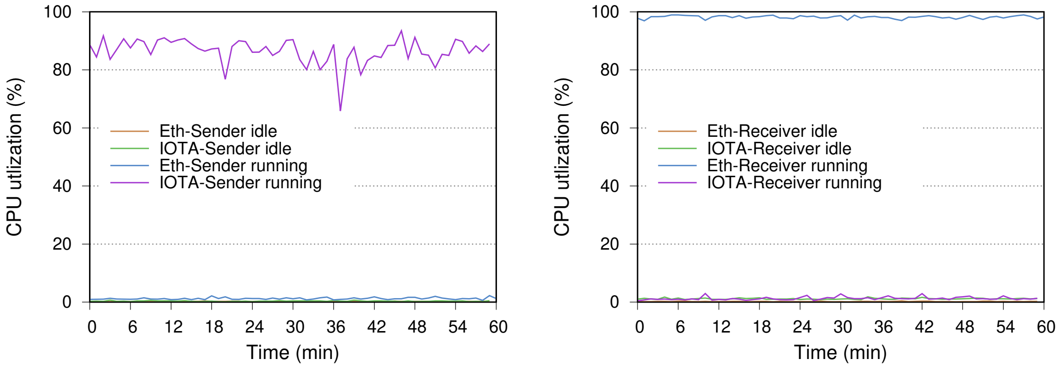
TABLE I: RPi4 Configuration & Sensor

CPU	Quad core Cortex-A72@1.5GHz		
RAM	4 GB		
OS	Ethereum		Ubuntu mate 20.04
	IOTA	Sender	Raspbian
		Receiver	Ubuntu server 20.04
Software	Ethereum		Geth 1.9.25-stable
	IOTA	Sender	IOTA Client Python Library
		Receiver	IOTA Hornet
PM sensor	Nova PM Sensor SDS011		

B. Consensus Layer

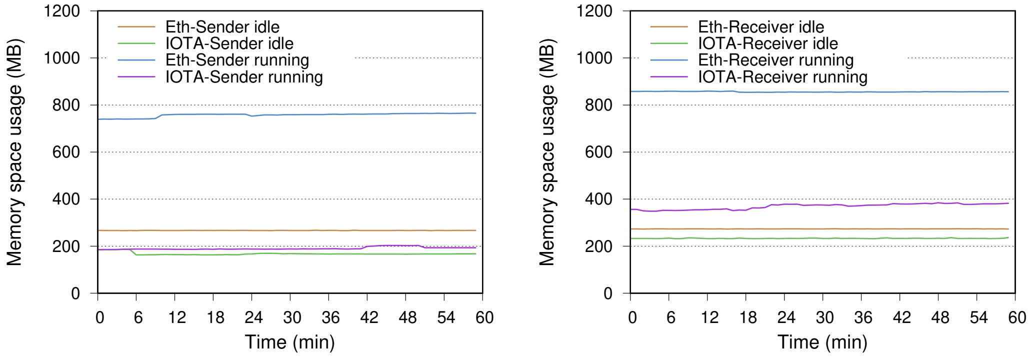
The results of the number of involved transactions are shown in Fig. 4. We can see that both DLTs gradually increase the transaction numbers. However, the IOTA line is significantly sharper than the Eth one. At the end of the experiment, IOTA finished executing 23882 transactions; meanwhile, Ethereum achieved only 3600. It is because IOTA has been designed to support high transaction speeds. Therefore, we can conclude that IOTA outperforms Ethereum in this metric.

Regarding the CPU utilization, the results of senders, receivers are shown in Fig. 5a, Fig. 5b, respectively. In the figures, we also capture the in `idle` state, when the RPi4



(a) Senders (b) Receivers

Fig. 5: CPU utilization



(a) Senders (b) Receivers

Fig. 6: Memory space usage

devices do nothing. Meanwhile, the `running` state indicates our experiment (i.e., running PoW). We can see the idle sender and receiver consume a little CPU power in the two figures. Moreover, the PoW of Ethereum is done by the receiver, while in IOTA, the sender does the job.The Ethereum PoW process occupies almost all of the CPU time of RPi4, while the IOTA client uses 86.21% of CPU on average during our experiments. Because for blockchains including Ethereum, PoW is intended to prove the reliability of the block generator on the block decision with the huge amount of computational power. While for IOTA, PoW aims to confirm the consistency of transactions and prevent spamming from malicious clients. A transaction with a proper nonce is allowed to attach to the Tangle. Thus, the PoW algorithm of IOTA is more lightweight.

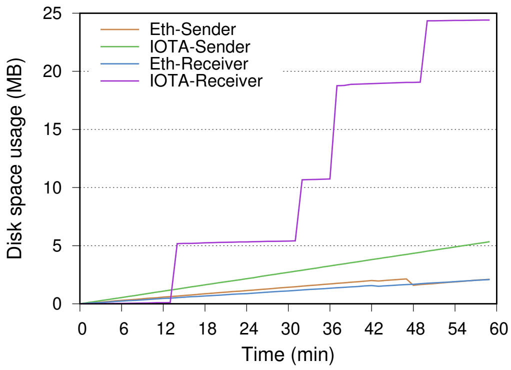


Fig. 7: Disk space usage

C. Network Layer

We measure the amount of transmitted data (TX) and received data (RX) and calculate these packets per transaction. The results are shown in Table II. As we can observe, Ethereum sends a smaller amount of packet than IOTA does. This is because the Ehereum's total transactions is less than IOTA's. Additionally, we noticed that the IOTA receiver transmits more data in one transaction than others.

D. Storage Layer

As transactions are constantly streaming from sender to receiver, we record the variations of memory and disk space during the `running` process. Note that we did not detect the swap space utilization in every experiment. The memory illustrated here refers to RAM. Both Ethereum and IOTA keep a stable memory space usage as shown in Fig. 6. However, IOTA has a smaller memory usage than Ethereum in both

TABLE II: Transmit and receive data

		RX(KB)		TX(KB)	
		Total data	Data per transaction	Total data	Data per transaction
Sender	Eth	1923.65	0.53	3740.73	1.03
	IOTA	21449.60	0.89	16489.24	0.69
Receiver	Eth	1821.37	0.51	3134.26	0.87
	IOTA	17931.77	0.75	42223.62	1.77

states. The IOTA sender increases approximately 20 MB from `idle` to `running` state, while the Ethereum one increases about 500 MB memory usage, which is largely occupied by the transaction sending Node.js script. The receivers have a similar situation, where the Ethereum client increases roughly 600 MB while IOTA increases about 150 MB. Ethereum client keeps recent information and a state tree in the memory, which records the Ethereum world state. Meanwhile, IOTA keeps a `memTable` (memory table) for recently acquiring information, which has a smaller volume than the state tree.

The disk space usage increments are shown in Fig. 7, where IOTA-receiver is not as linear as the other. That is because the write operations of IOTA receiver are first buffered in sequenced batches, then append the execution results with an entry to the in-memory `memTable`. When the `memTable` becomes full, the `PebbleDB` database will compress and flush them as a `ssTable` (Sorted Strings Table), ultimately stored to disk. Meanwhile, the IOTA sender is not responsible for data execution and storage. Moreover, with Ethereum, the sender and receiver used disk space increment is 2.09 MB and 2.11 MB by 3600 transactions in an hour. On average, 609 bytes and 616 bytes per transaction, respectively. Meanwhile, the IOTA receiver's space with the stepped increment and finally reached 24.41 MB or 1072 bytes per transaction on average. The disk space of IOTA sender linearly increased to 5.34 MB eventually, which shows 234 bytes per transaction.

VI. Conclusion

This paper presents a comparison between the two popular DLTs for IoT applications, Ethereum and IOTA. We have built and evaluated the two IoT systems with PM sensors and evaluate DLT following the three-layer architecture. The evaluation results shows that Ethereum consumes more CPU resources while executes less number of transactions than IOTA does. That also leads to a more significant amount of transaction involvement in the IOTA's infrastructure network. In the storage layer, IOTA needs more disk space per transaction at the sender and less at the receiver. Moreover, the IOTA receiver shows a stepped occupation on disk space with the feature of PebbleDB. In conclusion, IOTA shows better performance than Ethereum in our evaluation. However, Ethereum reaches 100% CPU in this case, its performance may be improved with a more powerful device.

In future work, we're going to study more performance metrics such as latency, power consumption, and so on. Additionally, we plan to include more DLTs to explore their advantages in different IoT scenarios.

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