Layer 2 Blockchain Networks for Decentralized IoT Systems

Tyler Choi, Brent Lagesse
Computer Science and Software Engineering
University of Washington Bothell
Bothell, WA USA
Email: tchoi94@uw.edu, lagesse@uw.edu

***Abstract*—Crowdsourcing systems which utilize data transmission and collection have risen in popularity to solve complex tasks in recent years. However, the majority of existing crowdsourcing systems rely on central servers, which are subject to the weaknesses of traditional trust-based models such as single point of failure and privacy disclosure. With the rise of distributed ledger technology, blockchain has been researched as a solution to address the centralization risks of crowdsourcing systems. Blockchain technology, albeit possible to establish a decentralized database to prevent centralized server risks, present their own weaknesses however, with high transaction costs and low throughput which are largely caused due to a phenomena known as the blockchain bottleneck. In response to the increasing applications of Internet of Things (IoT) and lack of scalability of utilizing traditional blockchains as a solution, alternative solutions such as Layer 2 networks and directed acyclic graph based networks have emerged to present distributed ledgers that claim both low transaction fees and high throughput. The particular solutions explored in this paper are Rollups and Sidechains in Layer 2 networks, and the IOTA Tangle as an example of directed acyclic graph networks. These are examined via a proposed design that involves configuration of respective test networks in a Metamask cryptocurrency wallet and the collection of transaction cost and speed data from the deployment of a smart contract.**

***Index Terms*—internet of things, distributed networks, decentralization, blockchain, ethereum, layer 2 networks, directed acyclic graphs**

I. Introduction

CROWDSENSING is the practice of obtaining information or input into a task or project by enlisting the services of a large number of people. Crowdsensing allows applications to be built by obtaining information from a large group of people who submit their data via the internet. However, crowdsensing in its conventional state poses several risks of centralization. Crowdsensing presents risk of data loss in centralized systems, and is subject to networks as well as being the single point of failure and privacy disclosure [33]. In other words, users personal data and task related data are all stored in a central database which have risks of data leakage and loss. In excavation of solutions of these risks, researchers in recent years have explored distributed networks as potential alternatives [30].

Blockchain technology has been at the forefront of this proactive response for its inherent qualities in enhanced security measures. Early blockchains like Bitcoin were pivotal in the technology's evolution with the adoption of innovative consensus mechanisms like Proof of Work (PoW) that amplified the acclaimed security of blockchain. Ethereum, compounded on top of Bitcoin's revolution with the introduction of smart contracts and decentralized applications that have allowed blockchain to ascend to new heights. However, as the technology has been further adopted by the mass with explosive growth in new adaptations and numerous forks, the exponential increase in interest and traffic has led to significant network congestion. Unsurprisingly, the blockchain bottleneck has created issues of slow confirmation times that involve high transaction fees and low throughput. In order for blockchain technology to achieve mainstream adoption, the need for scalability solutions have become paramount so that new systems which integrate blockchain can be usable by the mass.

Research and development efforts into scalable solutions [31] have made substantial progress with the introduction of Layer 2 networks and alternative network structures that utilize directed acyclic graphs. Alternative solutions are still in early stages of their evolution but have been demonstrating notable promise with *rollups* and *sidechains* that showcase lower transaction fees and faster transaction speeds. Other early stage new developments involve a distributed network that utilizes a *directed acyclic graph* as its fundamental data structure, which this paper will explore as well. Thus, the contributions of this paper are in the analysis and examination of alternative distributed networks that present scalable solutions to the bottleneck of traditional blockchains [12].

II. Background

A. Blockchain

Blockchain is a shared, immutable ledger that facilitates the process of recording transactions and tracking assets in a distributed network [25]. Blockchain has skyrocketed in its popularity in recent years due to its ability to deliver information both transparently and cryptographically. Blockchain works by recording each transaction as a "block" of data. This block is then connected to the ones before and after it, thereby creating an irreversible chain, hence a *"blockchain"*. However, this core mechanic of blockchain has also become its biggest weak link as new data blocks can only be appended to one point at the end of the chain thereby creating bottleneck situations when substantial traffic is transmitted.

B. Bitcoin

In 2008, the pseudonymous developer named *Satoshi Nakamoto* proposed a revolutionary peer-to-peer electronic payment system called *"Bitcoin"*[34]. A key component to bitcoin's novel development was executed via a consensus protocol termed *Proof of Work (PoW)* in which miners must produce specific hash outputs in order to add incoming transaction data blocks to the blockchain and be rewarded via native tokens (in this case, Bitcoin) for proof of their contributed work.

C. Proof of Work

Proof of Work is a consensus mechanism that allows user or machines to coordinate in a distributed setting. PoW essentially is an algorithm that prevents double spending [3], by requiring miners to utilize electricity and computational resources to hash data until they produce a specific solution. Proof of Work has allowed for the near impenetrable security of blockchain[28], at the expense of an increased barrier to entry on hardware requirements [9]. This can be observed in bitcoin mining farms placed throughout the world [16].

D. Ethereum

Ethereum is an improved iteration of Bitcoin.[26] It builds on Bitcoin's innovation, with some key differences. Ethereum is programmable, which has enabled a new ecosystem for deployable automated smart contracts. This has led to its recent rise in popularity with Decentralized Applications (Dapps) [11]. With its increased usage as a platform for smart contracts however, Ethereum has encountered increased issues of network congestion that result in high transaction fees and low throughput which have made the Ethereum user experience difficult for the average user/developer with nearly 200,000 pending transactions per minute (Fig. 1). Ethereum's network congestion issue is primarily caused not only by its increasing popularity amongst retail users and developers, but also due to the fact that it practices the PoW consensus protocol. Ethereum has been undergoing development to present its next iteration Ethereum 2.0 [5] in which the consensus model moves from a *Proof of Work* mechanism to a *Proof of Stake (PoS)* protocol, which could theoretically remove network congestion as computationally exhaustive miners will be exchanged with non-miner block validators [28]. Additional to development efforts in the next iteration of Ethereum, Layer 2 networks have also received significant interest as alternative scalability solutions.

E. Smart Contracts

Smart contracts are programs stored on a blockchain that run when predetermined conditions are met [24]. They are utilized to automate executions of agreements so all participants can be immediately certain of outcome, without any intermediary's involvement or time loss. The majority of smart contracts are deployed on the Ethereum mainnet or an interoperable blockchain that supports the *Ethereum Virtual Machine* (EVM) [6].

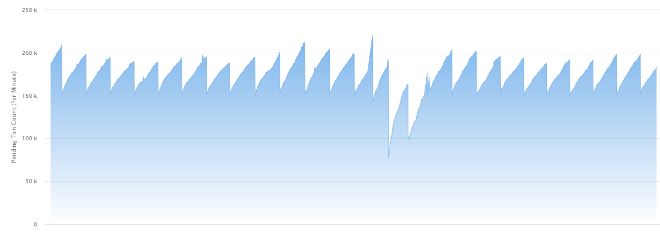

Fig. 1: Ethereum Network Pending Transactions Chart. Approximately 150,000 to 200,000 pending txn per minute.

F. Ethereum Virtual Machine

The Ethereum Virtual Machine is a computation engine which acts like a decentralized computer that has numerous executable projects. It acts as the virtual machine of Ethereum's entire operating structure that runs execution and smart contract deployment. The EVM is isolated from Ethereum, meaning that the code inside the EVM has no access to the network which allows for other chains to deploy the EVM and interoperable smart contracts [29]. The majority of smart contracts is written in the Turing complete coding language *Solidity* [21], an object-oriented programming language designed for writing smart contracts in Ethereum. This enables the EVM to process the operation code to complete certain tasks, thereby acting as a master decentralized computer to complete tasks on the blockchain.

G. Layer 2 Networks

Layer 2 networks are currently presented as a potentially viable solution to Ethereum's scalability issues. Layer 2 networks operate by handling transactions off of the Ethereum Mainnet (Layer 1) on a second layer and then posting the validated data back onto the Layer 1 Mainnet [19]. This allows for Layer 2 networks to take advantage of the security of Ethereum Mainnet whilst reducing network congestion that results in lower transaction fees and increased transactions per second [15].

Rollups: Rollups are a type of layer 2 network in which a batch of transactions are rolled up into a single transaction to the Mainnet [10]. Rollups are a powerful new layer-2 scaling paradigm, and are expected to be a cornerstone of Ethereum scaling. Rollups can support general-purpose EVM code, allowing existing applications to easily migrate over. A rollup chain that will be explored in this paper is the Arbitrum Layer 2 network [2].

Sidechains: A sidechain is another example of a layer 2 network in which an independent EVM-compatible blockchain runs in parallel to Mainnet. Sidechains are compatible with Ethereum via two-way bridges, and run under their own chosen rules of consensus, and block parameters [20]. The sidechain network that will be explored in this paper is the Polygon Matic network [17].

H. Directed Acyclic Graph

A *Directed Acyclic Graph* (DAG) is a data structure that uses a directed graph with no directed cycles (Fig. 2).

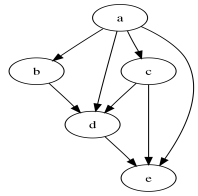

Fig. 2: Directed Acyclic Graph data structure representation

IOTA: **IOTA** is an open, feeless and scalable distributed ledger, designed to support frictionless data and value transfer [27]. A fundamental difference between IOTA and blockchain is in its primary data structure. While blockchains approve new transactions by attaching data to a single point (a new block), IOTA utilizes a DAG as the network's primary data structure which allows for new data blocks to be appended to any 8 points in the network [22]. Coined as the *Tangle*, the IOTA Tangle enables a network of parallel processed transactions [12]. This fundamental difference in structure offers many different points for new issued transactions to be attached, which dramatically speeds up the processing of transactions (Fig. 3). The IOTA Foundation aims to power open and transparent smart cities with the scalability of the IOTA network [14].

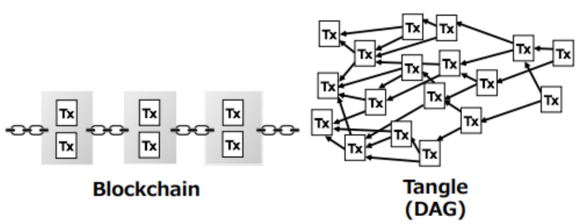

Fig. 3: Blockchain vs Tangle network structure

IOTA Tangle 2.0: The initial deployment of the IOTA network did not support the Ethereum Virtual Machine nor its interoperable smart contracts. However, with its IOTA 2.0 Beta release [13], the IOTA network now supports EVM thereby allowing for developers to import or export *Solidity* compatible smart contracts on the Tangle where users can experience the benefits of a DAG-based network structure.

III. Related Work

A. CrowdBC

Early researchers presented a blockchain-based decentralized framework for crowdsourcing on Ethereum called *CrowdBC*[32]. The research analyzes traditional centralized crowdsourcing system risks and presents a series of design algorithms based on smart contracts to handle centralization problems. The work done by the CrowdBC team has been foundational for future researchers with their proposed framework, but CrowdBC faces weaknesses of Ethereum network congestion which is displayed by the team's conclusion that a more low-cost blockchain is necessary. At the time of CrowdBC's proposal, Ethereum transaction fees averaged at 0.011 ETH with 1 Ethereum costing $784.21, which means that for any data transaction, the user would incur about $8. In early 2022, 1 Ethereum is priced at approximately $2,600 [4], which indicate that the same transactions would cost approximately $28 today. This level of transaction costs were unfeasible then, but are even more unfeasible today.

B. Crowdsensing on Ethereum Mainnet

CrowdBC paved the way for future research in which a blockchain-based crowdsensing system that deploys a smart contract to exchange wifi-sensing data was implemented on the Ethereum mainnet.[7] This research proposes blockchain-based crowd-sensing to make up for the paucity of decentralized crowdsensing systems with security and low service fees, but also faced the hurdle of expensive Ethereum transaction costs.

IV. Proposed Design

Past researchers have proposed different blockchain-based crowdsensing systems [1], but many proposals that aimed to utilize the EVM and smart contracts faced similar consequences of Ethereum network congestion. This further raises the need for research that proposes alternative solutions in which blockchain-based tasks can be performed without suffering from bottleneck-induced downsides. Therefore, this section aims to design and test a simple smart contract on different development environments and test networks to examine their transaction costs and speed to determine their feasability as potential scalability solutions. See (Fig. 4) for visualized concept map that outlines the design of how the proposed design will be evaluated.

The development environments of this experiment will utilize *Remix* and *Hardhat* while test networks will examine the results of *Ethereum Ropsten (L1)*, *Arbitrum Rinkeby (Rollup L2)*, *Matic Mumbai (Sidechain L2)*, *IOTA Tangle (EVM)*. See (Fig. 5) for proposed design flowchart that visualizes the flow of the test network configuration, contract deployment, and on-chain verification.

The operating system used for this experiment was Ubuntu LTS 20.04. The contract and instructions to replicate the performed tests are available at [23].

A. Test Networks

Test networks are a crucial component to smart contract deployment on blockchain. Test networks allow developers to simulate a real blockchain development environment without incurring real transaction fees. Test funds are used instead which can be requested from network faucets that allow developers to receive fake funds that can only be used for testing purposes. The test networks and simulated blockchains that are used in this experiment are:

- Ropsten: Ethereum Mainnet
- Arbitrum Rinkeby: Ethereum Layer 2 Rollup - Arbitrum
- Matic Mumbai: Ethereum Layer 2 Sidechain - Polygon
- Iota EVM: Iota Tangle 2.0

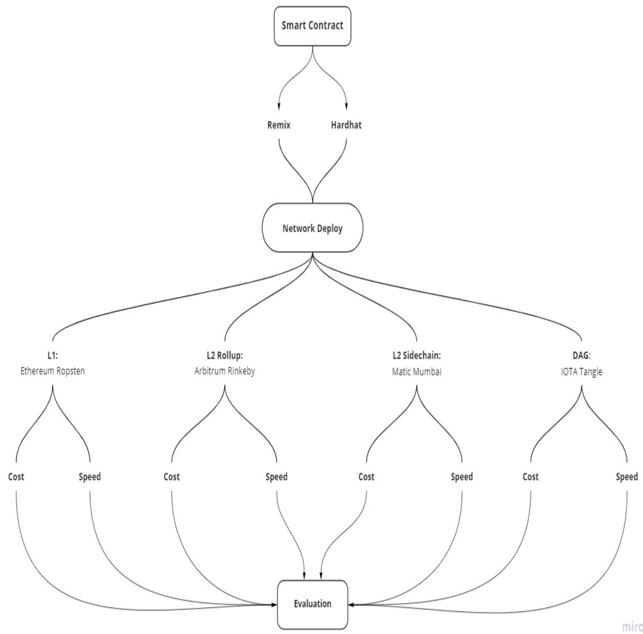

Fig. 4: Proposed Design Concept Map

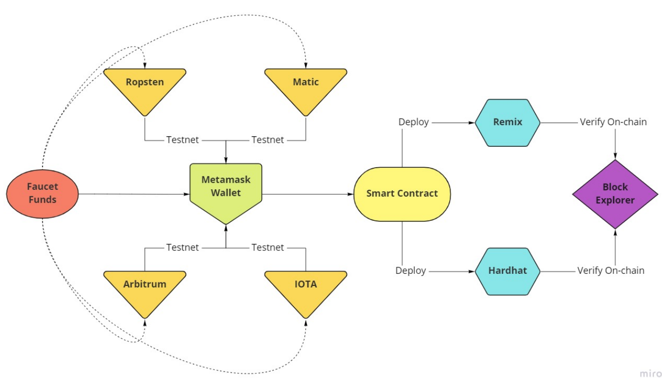

Fig. 5: Proposed Design Flowchart

TABLE I: Remix Deployment

Remix			
Network	Base	Cost	Speed
Ropsten	L1 Mainnet	$2.26	6s
Arbitrum Rinkeby	L2 Rollup	$ 0.23	2s
Matic Mumbai	L2 Sidechain	$0.0012	12s
Iota EVM	DAG	$0 (beta)	3s

TABLE II: Hardhat Deployment

Hardhat			
Network	Base	Cost	Speed
Ropsten	L1 Mainnet	$1.3	6s
Arbitrum Rinkeby	L2 Rollup	$ 0.06	2s
Matic Mumbai	L2 Sidechain	$0.005	4s
Iota EVM	DAG	$0 (beta)	10s

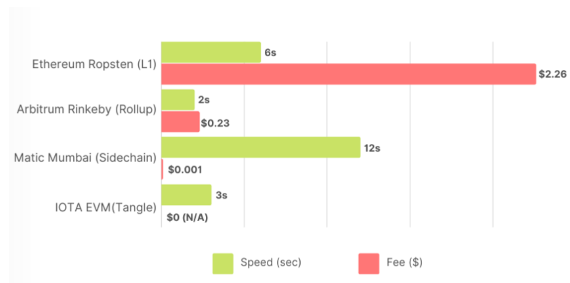

Fig. 6: Remix Data Visualization

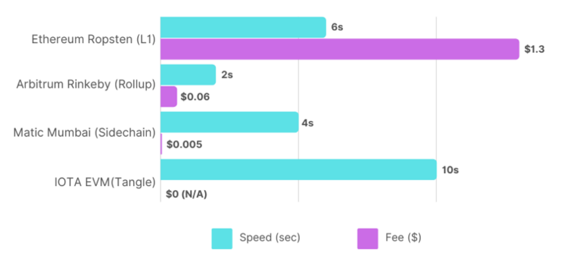

Fig. 7: Hardhat Data Visualization

B. Development Environment

Two development environments are used for this test.

- Remix: A web based smart contract compiler [18]
- Hardhat: A local Ethereum network [8]

Test results of Remix deployment are detailed in [Table I], while test results of Hardhat deployment are presented in [Table II].
See (Fig. 6) and (Fig. 7) for graphical visualization of [Table I], [Table II] data.

V. EVALUATION

A. Shortcomings

1) IOTA 2.0: IOTA 2.0 is currently in beta access. Although the current status of the DAG-based network enables EVM and smart contract support, the network has all fees set to zero. This results in unrealistic estimations of transaction benefits that may incur by using the IOTA Tangle [13]. Therefore, only the speed at which IOTA's test network deploys our smart contract was examined as an analysis component to the alternative solution experiment.

2) Smart Contract: Designing and creating a smart contract that simulates an IoT crowdsensing system was outside of the scope of this paper. Previous research that involved a smart contract that models a blockchain-based crowdsensing system [7] was outdated and produced substantial security issues that was deemed unusable as a viable test smart contract for the purpose of this paper's experiments. Construction and deployment of a smart contract that simulates an IoT system on layer 2 networks is recommended in the Future Work section.

B. Results

Results are discussed with respect to the Ropsten testnet as indicators of the viability of alternative solutions to Ethereum Mainnet. All data that is presented can be observed in [Table I] and [Table II] or the on-chain block explorer proof provided in [23].

1) Ropsten: The Ropsten testnet that represents the Ethereum Mainnet incurred substantially higher transaction costs compared to its counterparts at $2.26 and $1.3 for its deployment on the web compiler, Remix and local Ethereum environment, Hardhat, respectively.

2) Arbitrum: The Arbitrum Rinkeby Layer 2 testnet displayed lower transaction costs under a quarter and faster deployment speeds at 2 seconds.

3) Matic: The Matic Mumbai testnet produced significant results with transaction fees under a penny, but deployment speeds are similar to the Ropsten testnet.

4) IOTA: The IOTA testnet produced zero transaction fees due to its beta status, but is expected to display comparable costs to layer 2 network solutions when officially deployed.

5) Development Environments: Remix as a web-based smart contract compiler has a user-friendly interface with features that automatically detect and configure appropriate settings for deployment, but produced comparatively higher transaction costs to the more hands-on Hardhat local environment. Both development environments showcased similar transaction speeds.

Transaction costs and speed are notably improved in layer 2 networks compared to layer 1. The results indicate that rollups and sidechains can be feasible as scalable distributed ledgers that circumvent the blockchain bottleneck of Ethereum Mainnet.

C. Recommendations

Based on the collected results, recommendations for future developers and researchers are to explore layer 2 networks as viable alternative solutions to Ethereum Mainnet. Polygon is suggested for systems that embrace parallel networks like sidechains and prioritize low transaction costs, and Arbitrum is proposed for systems that value faster transaction speeds. For devleopment environments, Remix is recommended for quick prototyping while Hardhat is advised for production deployment.

VI. Future Work

Based on the results collected in this paper, appropriate future work to continue the exploration and examination of alternative scalable solutions to Ethereum Mainnet would involve an updated network analysis when the IOTA 2.0 EVM is officially released to determine the potential benefits of a DAG-based distributed network in comparison to layer 2 solutions. Another component to productive future work could include other EVM-supporting blockchains or layer 2 networks to the scalable alternative analysis. Finally, a design and deployment of a smart contract that simulates an operational IoT system could further advance the efforts of developing distributed ledger solutions to crowdsensing networks.

VII. Conclusion

This paper continues the diligent efforts of past research that aimed to explore distributed network solutions to the risks of centralized IoT systems. While past research had examined the Ethereum Mainnet as its potential blockchain solution, the reality of increasing network congestion had led researchers to the conclusion that scalability solutions were needed for distributed ledger technology to contribute to mass adopted decentralized IoT systems. This research contributes to the search of identifying and analyzing alternative solutions to Ethereum with layer 2 chains and DAG-based networks. The experiments of this research found that layer 2 networks such as rollups and sidechains demonstrate promise in handling transaction volume off of the Ethereum Mainnet while embracing the inherent security structure of layer 1. With test results showcasing lower transaction fees and faster transaction speeds, this paper reinforces the feasibility of layer 2 networks as alternative solutions to Ethereum to circumvent the blockchain bottleneck. With the presentation of several viable solutions, this research supports further progress towards research and development into feasible decentralized IoT systems.

References

[1] 1808.04056.pdf. https://arxiv.org/pdf/1808.04056.pdf.
[2] Arbitrum – scaling ethereum. https://arbitrum.io/.
[3] Double-spending definition. https://www.investopedia.com/terms/d/doublespending.asp.
[4] Ethereum price today, eth to usd live, marketcap and chart — coinmarketcap. https://coinmarketcap.com/currencies/ethereum/.
[5] Ethereum upgrades (formerly ’eth2’) — ethereum.org. https://ethereum.org/en/upgrades/.
[6] Ethereum virtual machine (evm) — ethereum.org. https://ethereum.org/en/developers/docs/evm/.
[7] Github - ohyoukillkenny/bcs: A blockchain-based decentralized crowdsensing system. https://github.com/Ohyoukillkenny/BCS.
[8] Hardhat — ethereum development environment for professionals by nomic foundation. https://hardhat.org/.
[9] How does bitcoin mining work? what is crypto mining? https://www.investopedia.com/tech/how-does-bitcoin-mining-work/.
[10] An incomplete guide to rollups. https://vitalik.ca/general/2021/01/05/rollup.html.
[11] Introduction to dapps — ethereum.org. https://ethereum.org/en/developers/docs/dapps/.
[12] An introduction to iota — iota wiki. https://wiki.iota.org/learn/about-iota/an-introduction-to-iota.
[13] Iota smart contracts beta release. https://blog.iota.org/iota-smart-contracts-beta-release/.
[14] Iota_smartcityreport.pdf. https://files.iota.org/comms/IOTA_smartcityreport.pdf.
[15] L2fees.info. https://l2fees.info/.
[16] Largest bitcoin mining farms in the world — sunbird dcim. https://www.sunbirddcim.com/blog/largest-bitcoin-mining-farms-world.
[17] Polygon technology — documentation. https://docs.polygon.technology/.
[18] Remix - ethereum ide. https://remix.ethereum.org/.
[19] Scaling — ethereum.org. https://ethereum.org/en/developers/docs/scaling/.
[20] Sidechains — ethereum.org. https://ethereum.org/en/developers/docs/scaling/sidechains/.
[21] Solidity — solidity 0.8.11 documentation. https://docs.soliditylang.org/en/v0.8.11/.
[22] Tangle — iota beginners guide. https://iota-beginners-guide.com/dlt/tangle/.

[23] teechoi/layer-two-network-experiments: Code to perform experiments for alternative solutions to ethereum research paper. https://github.com/teechoi/Layer-Two-Network-Experiments.

[24] What are smart contracts on blockchain? — ibm. https://www.ibm.com/topics/smart-contracts.

[25] What is blockchain technology? - ibm blockchain — ibm. https://www.ibm.com/topics/what-is-blockchain.

[26] What is ethereum? — ethereum.org. https://ethereum.org/en/what-is-ethereum/.

[27] What is iota — iota. https://www.iota.org/get-started/what-is-iota.

[28] What is ”proof of work” or ”proof of stake”? — coinbase. https://www.coinbase.com/learn/crypto-basics/what-is-proof-of-work-or-proof-of-stake.

[29] What is the ethereum virtual machine (evm)? — sofi. https://www.sofi.com/learn/content/what-is-ethereum-virtual-machine.

[30] Angelia Corbett and Bin Young. Why is so little attention paid to the centralization of data? In *2008 IEEE Aerospace Conference*, pages 1–9, 2008.

[31] Abdelatif Hafid, Abdelhakim Senhaji Hafid, and Mustapha Samih. Scaling blockchains: A comprehensive survey. *IEEE Access*, 8:125244–125262, 2020.

[32] Ming Li, Jian Weng, Anjia Yang, Wei Lu, Yue Zhang, Lin Hou, Jia-Nan Liu, Yang Xiang, and Robert H. Deng. Crowdbc: A blockchain-based decentralized framework for crowdsourcing. *IEEE Transactions on Parallel and Distributed Systems*, 30(6):1251–1266, 2019.

[33] Yufei Lin and Chongyang Zhang. Crowdsourcing system based on blockchain. In *2020 IEEE 11th International Conference on Software Engineering and Service Science (ICSESS)*, pages 98–101, 2020.

[34] Satoshi Nakamoto. Bitcoin: A peer-to-peer electronic cash system, 2009.