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Forming a decentralized research network: DS4H

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Abstract: There is a trend toward decentralized systems, but these systems are developed without conducting enough software tests. Also, the performance, scalability, and sustainability of the decentralized systems are not taken into account. One of the reasons is the time-consuming testing process. The other is the hardware requirements and the complexity of the software installations of the testing environment. Developer communities need stable and secure research networks to test and develop prototypes before releasing the working versions. Cloud-based blockchain test networks are available, but it allows using a specific framework. Also, users are required to learn how to use each framework. Blockchain test networks use public ledgers, and this is also not preferable in many project implementations because of privacy reasons. Testbeds are inflexible and unrealistic in terms of scalability and performance. There is a need for a physical test network to create a realistic test environment. This study aims to form a sustainable and scalable research environment where decentralized technologies are researched and developed. The method of this study will include three stages to create a decentralized research network. The first stage is to develop the decentralized foundation of the network by using the Quorum blockchain framework and RAFT consensus protocol. Node requirements are simplified to run on low-cost devices. The second stage will be to develop a web-based platform to serve as an efficient way for the developers to deploy smart contracts easily. The final stage will be ensuring the sustainability of the system. Usage policy is formed that includes management of the network, the system usage rules, and regulations. A decentralized governance model is proposed. Smart contracts are developed to manage and ensure the sustainability of the research network. The available test tools were not sufficient and not flexible to use in this system, so a new test tool was developed for this project. The new test tool will verify the research environment with scalability, latency, and performance tests. As a result, the “Decentralized Solutions for Humanity” (DS4H) research network is deployed in four different regions of Turkey. This network is tested with four initial nodes. New nodes are to be added worldwide. The developed tools named Chainex, GoHammer, and Scanner are shared as open-source. Future works will include adding multiple blockchain network support, working on consensus protocols and new decentralized services. Finally, the DS4H research network provides a test and development research environment for blockchain projects with sustainable and low-cost maintenance.

Key words: Blockchain, research network, decentralized governance, smart contract, decentralized applications

1. Introduction

There is a trend to decentralized systems from governments to networks [1]. Decentralized solutions can be used to enhance trust in the internet, so people can connect securely and privately. Secure and privacy-preserving systems can be developed with the blockchain[2].

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Blockchain is a decentralized ledger technology that can be used to ensure trust without a central authority. Blockchain systems allow the parties to have common decisions without any intermediaries by using consensus protocols. Proof of Work (PoW), Proof of Stake (PoS), Practical Byzantine Fault Tolerance (PBFT), Delegated Proof of Stake (DPoS) are the most common consensus protocols. Cryptocurrency implementations mostly use the Proof of Work (PoW) consensus protocol that uses a high level of electricity consumption. However, Enterprise frameworks run on reliable nodes and do not require such detailed operations in the consensus process, so various other consensus protocols can be used [3]. It is also a good practice to think about ”how these blockchain solutions would be operated and by whom” [4].

Ethereum framework introduced the smart contracts that enable autonomous programs [5]. These codes are written as immutable records in the blockchain ledger and can be called from their stored addresses. Decentralized applications (DAPP) use these codes to give decentralized services. Other blockchain frameworks such as Hyperledger Fabric[6], Corda[7], Quorum[8] can be used to develop and deploy alike codes.

DAPPs are developed without conducting enough software tests. Software testing is a time-consuming process. The complexity of the software installations of the testing environment is another issue. Deploying smart contracts on a blockchain network and interacting with the system is a complex task. Developers need to test their codes on a test network (testbed) before releasing the decentralized service. Some blockchain frameworks serve testbeds where developers can test and develop their applications. These testbeds are mainly cloud-based, and users are required to learn how to use each. These testbeds use public ledgers that may not be preferable in many projects because of privacy reasons. These environments are also inflexible. Scalability and performance testing on these testbeds can give unrealistic results. There is a need for a physical test network to create a realistic test environment. There is a need for development workbench environments that the developers can use as a user-friendly interface and make this process cheaper [9]. Some countries like China see the need for such environments. China deployed a national blockchain network in 100 cities to decrease the costs of blockchain solutions[10].

Creating an environment to test decentralized systems is not easy, especially when you want to make a distributed network. The researchers need to install several nodes, and these nodes should be geographically distributed to form a realistic network. Controlling the state of such a network is not easy as it is decentralized. There will be technical issues in the systems, as these blockchain frameworks are still developing, and new versions will bring new dependency problems. The cost of installing such a network and preserving its sustainability is also another challenge.

Decentralized solutions are still evolving. There are many scalability and security challenges to be solved [3]. There is a need for more academic studies in this field. NGOs (non-governmental organizations) can also work for practices on using this technology for good. There is also a need for an environment where the academy and the NGOs can easily deploy and test decentralized solution prototypes.

We propose and deploy a blockchain network called the decentralized solutions for humanity (DS4H). This paper aims to give the system proposal and the implementation details of the project. This platform will allow the usage of public and private ledgers. Our main contributions with this study are as follows:

- A geographically distributed and decentralized academic testbed. The network will expand with possible new contributions.
- A sustainable system with low-cost devices and low power consumption.
- We propose an environment (Chainex workbench) where smart contracts can easily be deployed. This

will serve as a user-friendly interface for the developers.

- A usage policy is prepared for the sustainability of this evolving network.
- A decentralized system governance model is proposed. Smart contracts will be used to make some management tasks automized.
- We show that, even under heavy load, the system performance is at acceptable levels.

In the next section, related works will be given. In Section 3, details of the system proposal are given. Then, the implementation of the DS4H system is given in Section 4. In section 5, discussion and evaluation is presented. Conclusion and future works will be given in the last section.

2. Related works

There is not much study in the literature, but interesting studies are in practice. Many current blockchain test environments are simulators[1]. The researchers mostly have to install test networks themselves. There are some public and private testbeds of some blockchain frameworks, but we are not aware if they are distributed and if propagation delays are taken into account. As an example, the test networks of Ethereum[2] is listed in a recent survey[3]. These test networks serve public testbeds that serve public ledgers. Anyone can read or create transactions on these testbeds. We are not aware of a public testbed that serve private ledgers. The sustainability of such testbeds is also another issue. There are recent testbed demonstrations like BlockZoom[11], but there is no detailed information about the implementation. Comparison of the existing works (Bloxberg and Tübitak Bağ) and our study is given in Table 1.

Bloxberg[4] is a decentralized infrastructure that aims to enable the scientists to keep their intellectual properties such as their research claims. The records of their studies will be kept public but also in a way that will not reveal the details. They will be able to print certificates of their data. The project is a public ledger and also uses its cryptocurrency. Its' governance model involves a voting model, which involves on-chain and off-chain operations. This project also aims to have decentralized academic services such as research funding, peer review, scientific identity [12].

TUBITAK BAĞ[5] (Blokzincir Araştırma Ağı) is another testbed that aims to support blockchain research. The project aims to host different blockchain frameworks and integrate different institutions, but there was not enough information on how to contribute and use this testbed at the time of the writing.

The test tools to test performance of the blockchain networks were covered in [13]. The most comprehensive benchmarking environment is the Hyperledger Caliper (https://hyperledger.github.io/caliper/) at the time of the writing. It does not support Quorum currently but it can collect several performance metrics. Sample implementations for test transactions and scripts are given in [14–17]. Chainhammer [6] and Quorum

[1]Kaur, J. (2020) 10 Blockchain Simulators And Testnets For All Your Testing Needs 2020. Website https://hackernoon.com/blockchain-simulators-ui2030z0 [accessed 17 May 2021]

[2]Ethereum (2020) Test Networks. Website https://docs.ethhub.io/using-ethereum/test-networks/ [accessed 17 May 2021]

[3]Eulberg P. (2021) Overview of 17 Ethereum Blockchain Networks. Website https://www.anyblockanalytics.com/blog/overview-ethereum-blockchain-networks/ [accessed 17 May 2021]

[4]Bloxberg (2021) Bloxberg. Website https://bloxberg.org/ [accessed 17 May 2021]

[5]Tübitak (2021) Tübitak BAĞ. Website https://bag.org.tr/ [accessed 18 May 2021]

[6]Chainhammer (2021) Chainhammer. Website https://docs.ethhub.io/using-ethereum/test-networks/ [accessed 17 May 2021]

Profiling [7] tools support Quorum, but these are not easy to use, and they need complicated installation steps. Chainhammer's some required dependencies are also outdated. So, we also started to build our own test tool (GoHammer) during the project.

The DS4H project differs from these projects by being a testbed where decentralized technologies can be developed and tested. DAPP development support is provided by Chainex. Test tool support is given with the GoHammer. DS4H also gives private ledger support and does not use cryptocurrency. This network is also managed decentralized; it uses an on-chain governance model operated with smart contracts.

Table . Comparison of the existing works and our study.

	Bloxberg	TUBITAK Bağ	This study (DS4H)
Purpose	Decentralized Academic Services	Blockchain Research	Blockchain Research
Ledger	Public	Public	Public & Private
Crypto Currency	Yes	None	None
Geo Distributed Nodes	Yes	None	Yes
Governance	Voting model (on-chain & off-chain op.)	Centralized Management	Decentralized (on-chain)
DAPP Development Support	None	None	Yes (Chainex)
Test Tool Support	None	None	Yes (GoHammer)

3. System proposal

The DS4H system is an independent (decentralized) blockchain testbed where academy can develop and test blockchain solutions. The DS4H system is shown in Figure 1 [9]. This system consists of decentralized network, system users, blockchain DAPP development & test support (Chainex) and the decentralized system governance model. The details will be described in the following sub sections.

3.1. Decentralized network

Decentralized network is formed of the blockchain nodes that will validate transactions and hold the records (the ledger). Three types of nodes can be used according to the functionality. Simple node can generate and validate new transactions. This node can be IoT or limited capacity mobile device. Partial node has basic attributes and it can also keeps a partial copy of the blockchain. Laptops or alike can be used. Full Node has basic attributes and also keeps full copy of the blockchain. Servers or personal computers can be used [18].

DS4H will be formed of three different networks that are called as learner network, the transaction network, and the governance network. The governance model is shown in Figure 2. The nodes of the new consortium members will be put into the learner network first. The trusted and validated nodes will be moved to the transaction network. The stability depends on the up-time and nonabusive working of the nodes. The governance of the system will be implemented with the governance network. Governance network will be formed of the founder nodes of the system. This network will keep a ledger for the management tasks. IBFT consensus protocol is used in the implementation of this network.

[7] Quorum (2021) Quorum Profiling. Website https://docs.goquorum.consensys.net/en/stable/Concepts/Profiling/ [accessed 17 May 2021]

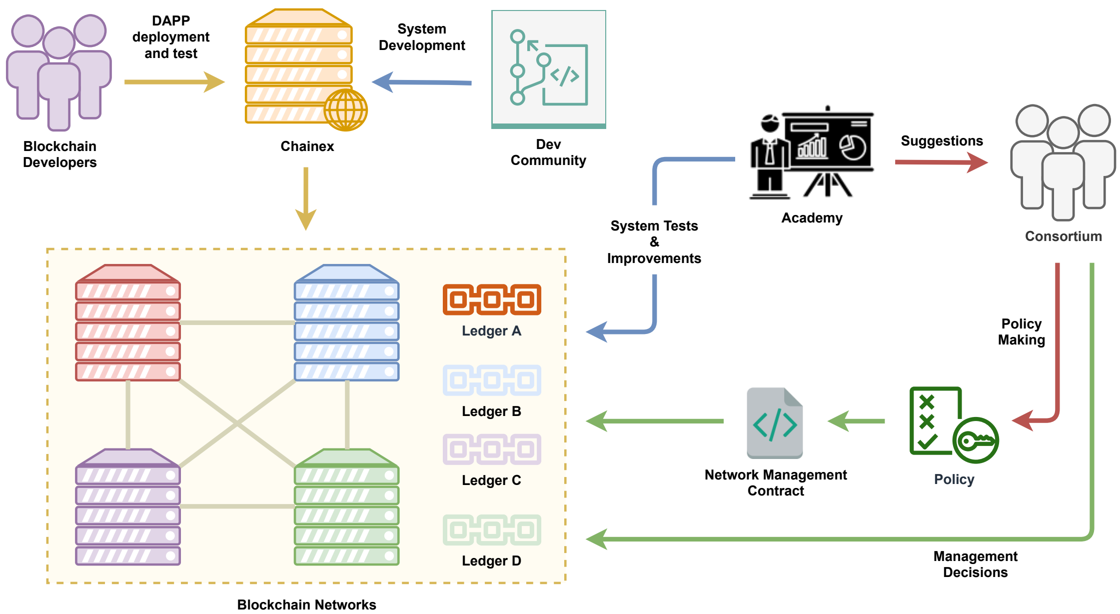

Figure 1. DS4H system architecture.

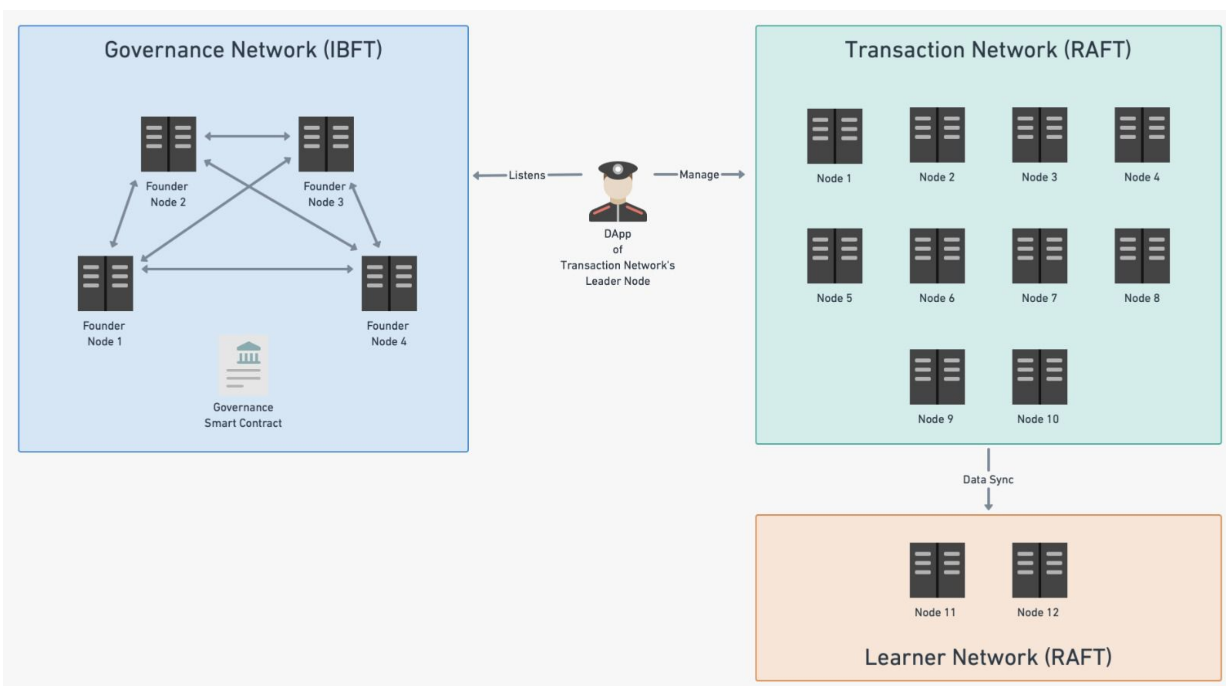

Figure 2. Decentralized governance model.

3.2. System users

There are different users and roles in the system. These are the consortium members, academy, developers, and the developer community. Consortium members provide the infrastructure support and fulfill the management tasks of the system. Academy uses the system for their research projects. Developers use the system to develop decentralized applications. The developer community will work on maintaining and developing the DS4H decentralized services.

3.3. Decentralized governance model

This sudy aims to have a decentralized management by utilizing consortium. Consortium is being formed with the institutions that provide computer, hardware, or software development effort to enable the system to work. Consortium members are defined in the system as accounts assigned by the institutions in the consortium. Consortium members will have equal voting rights. The selection of new members is implemented unanimously by the consortium. The majority of votes will be enough when new projects are selected. This policy is constantly evolving and will be updated with new consortium members.

The consortium members govern the system with the system management model. The governance model is defined in the system policy, which is formed and updated by the consortium. Network management contracts are designed and deployed to make some of the management tasks autonomous. Management and user policy are formed and updated by the consortium.

The usage policy is prepared to ensure the sustainability of the DS4H blockchain network. Usage Policy is written and shared on the policy wiki page.[8] The policy involves the rules for participation in the system, usage, prevention of system abuse, management, leaving the system and the disclaimer.

The system is evolving to have various nodes in several parts of the world and contain data from various countries. It is important to give a legal disclaimer on the storage of personal data. Storing personal data on the blockchain ledger is not recommended. Various decentralized apps will contain transactions of various users. These apps should warn the users of this natural characteristics of the decentralized system. The policy also includes a legal disclaimer on any possible criminal activity or personal data abuse that can result in a fine.

An autonomous system is designed for the decentralized management. The management of the DS4H is made autonomous with network smart contracts and the decentralized app, which runs this contact. We tried to form a democratic and a sustainable management system where every founder member is equal and has one vote. The founder members of the system can never be removed from the DS4H system. If the founder member ever want to leave the system (retire) by their wish, the oldest node in the system become the founder member. New members can be added if they are recommended by the former consortium members. Addition or removal of a member is voted by the founder members, and all the founder members should agree on the decision.

The decentralized app periodically runs the network smart contract to check the stability of the nodes and ensures the sustainability of the system. This is provided by the IBFT consensus algorithm, and pseudo-code of the model is given in the Algorithm 1. These checks include the activeness of the nodes in the DS4H network and if they are generating more TPS (transactions per second) than the system max limit. The TPS SysLimit value can be modified according to the overall system load and is configured in the smart contract. If some of the nodes are not active or generating too many transactions, this process ensures that the system takes measures as soon as possible. These are not only limited to the governance alerts; the system can prevent those nodes from generating transactions till the cause of this event is understood.

3.4. Blockchain DAPP development & test workbench (Chainex)

Chainex is a service to simplify the DAPP development and test processes. Chainex system architecture is shown in Figure 3 [9]. Chainex should be deployed at least on one of the blockchain nodes or on a separate server. for details see [9].

The sample test scenario is used for the performance evaluation is shown in Figure 4. It consists of the

[8] DS4H (2021) DS4H Policy. Website http://wiki.netseclab.mu.edu.tr/index.php?title=Ds4h_policy [accessed 17 May 2021]

Algorithm 1: Node stability control.

```
Input: NodeList, TpsSysLimit
Output: Governance Alerts if any
Data: Blockchain network and the ledger
i ← 1
/* iterate the control for all nodes */
while i ≤ nodecount do
    NodeStatus = CheckNodeStatus(Node[i] )            // Fn to check activeness
    if NodeStatus is Active then
        tps = CheckTPS (Node[i])                       // Fn to Calculate TPS
        if (tps ≥ TpsSysLimit) then
            WarnGovernanceNodes (Node[i], tps)         // Create governance alert
        end
    end
    else
                                                       // Create governance alert
        if NodeStatus is Unreachable then
            WarnGovernanceNodes (Node[i], Unreachable)
        end
        else
            WarnGovernanceNodes (Node[i], InActive)
        end
    end
    i =i + 1
end
```

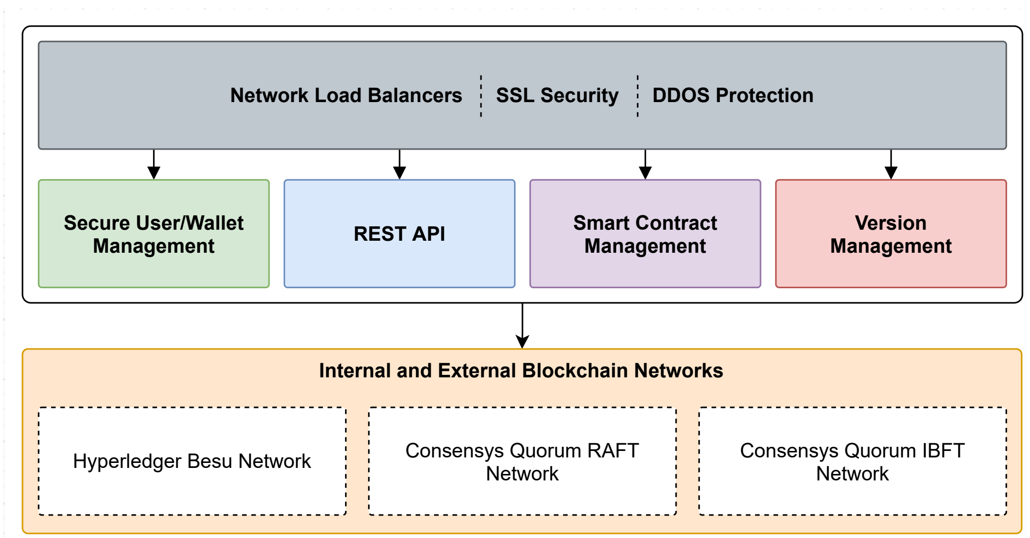

Figure 3. Chainex system architecture.

blockchain network, which will be tested nodes and the test node. The system needs at least one test device (TestNode), which will generate the load and then observe the results. The main performance metrics are latency, throughput, resource utilization [14] and the number of failed/delayed transactions due to timeouts [9]. Read latency and transaction latency is measured. Read throughput and transaction throughput are monitored.

CPU, memory, and network IO statistics are calculated for monitoring resource utilization.

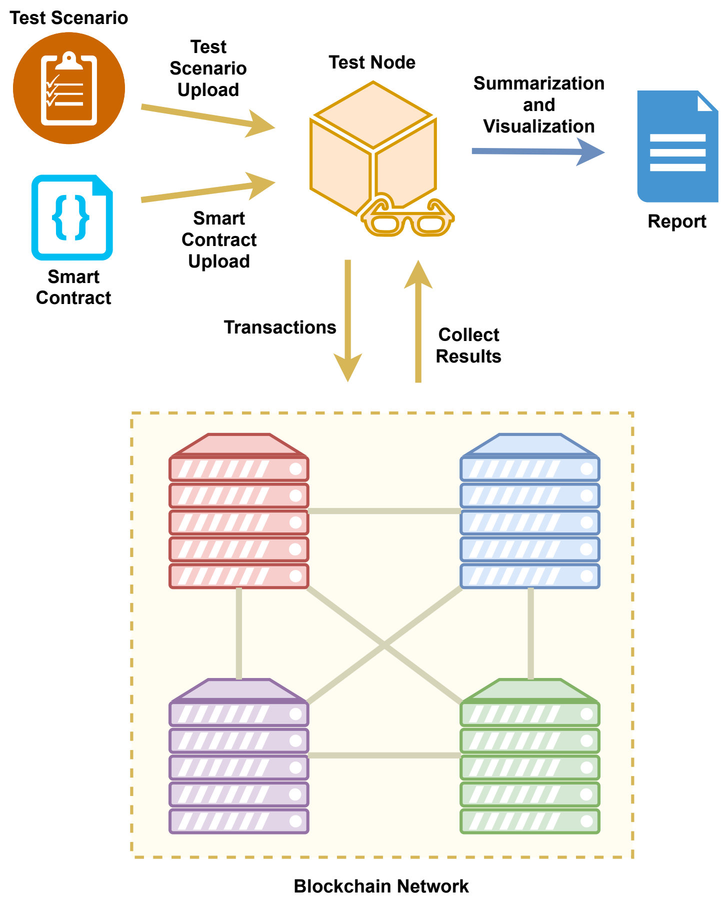

Figure 4. Test scenario.

4. Implementation

The topology of the DS4H network is shown in Figure 5. We started with partial nodes in this project. The first nodes are installed at four locations; Muğla (Muğla Sıtkı Koçman University), İstanbul (Istanbul Teknopark), Samsun (Ondokuz Mayıs BAUM), Osmaniye (Osmaniye Korkut Ata University). Partial nodes and simple nodes are installed at these locations with the ISOC grant. The project aimed to define the minimum hardware requirements that can run this blockchain network. Ordinary PC Hardware with 4 core CPU, 8 GB RAM with 512 GB disc is used for partial nodes. We also worked on Raspberry Pie solutions, which can be used to validate transactions. Raspberry Pie 4, 8 GB Ram, 32 GB microSDHC is used for simple nodes. The operating system is Ubuntu 16.04+ (no GUI). Chainex software workbench is installed on the Muğla node in this topology. Chainex workbench web interface is shown in Figure 6. Wiki page[9] of the project dives detailed information about the project and installation steps.

Nodes are installed on sites and will work autonomously. However, yet there should be a point of contact to reboot the device or issue basic commands for the network connectivity when needed. Static IP address and specific open TCP ports are the network requirements. The network IP addresses should be static and known,

[9]DS4H (2021) DS4H Project. Website http://wiki.netseclab.mu.edu.tr/index.php?title=DS4H [accessed 17 May 2021]

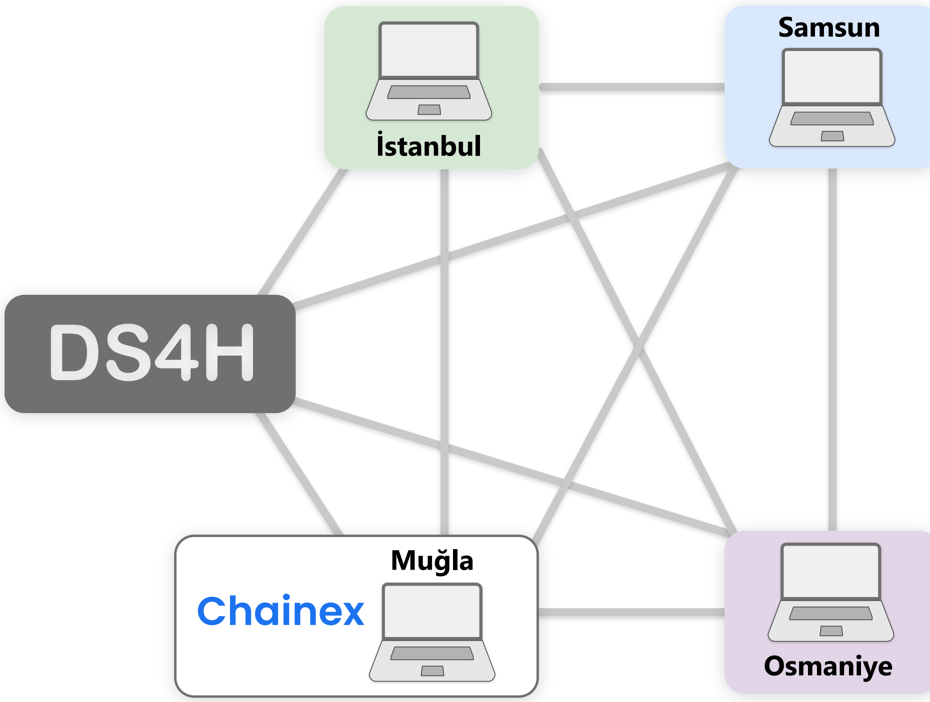

Figure 5. DS4H blockchain deployment.

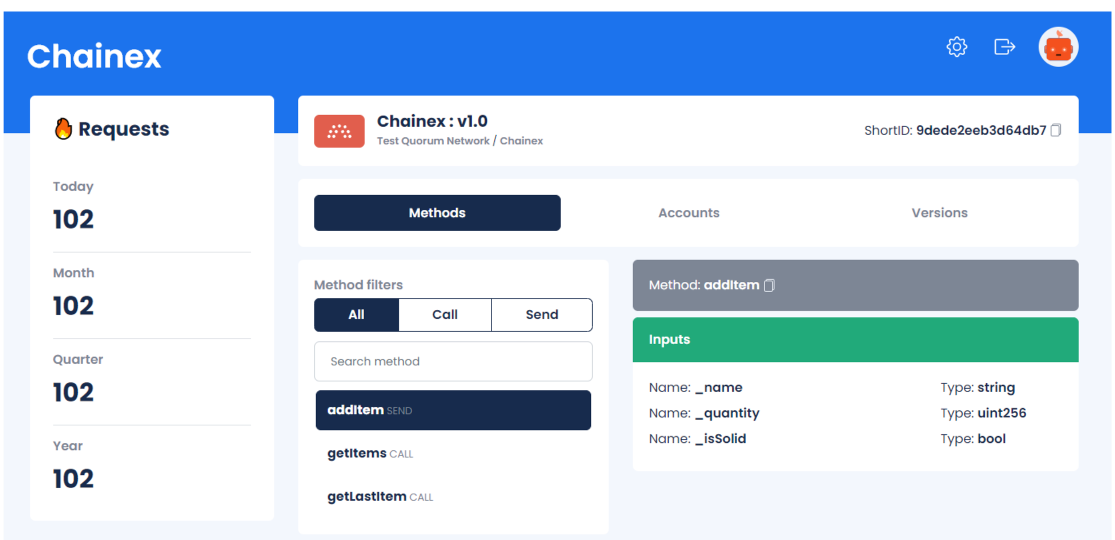

Figure 6. Chainex web interface

so that further security measures can be taken. TCP ports for consensus Port, P2P Port, WS Port, and RPC Port should be open (inbound/outbound) at the firewall.

Usage of container technologies like Docker is also planned for future implementations to use Docker images. We also worked on Raspberry Pie solutions, which can be used to validate transactions. Quorum blockchain framework is installed on the nodes. Quorum framework is preferred as the initial blockchain framework as there is an active developer community. It is based on the Ethereum framework and supports Solidity smart contracts. This is important as the majority of the available blockchain codes in the decentralized world are in Solidity language. Quorum supports a private ledger and can be used to develop enterprise applications. Quorum supports several consensus protocols other than PoW (Proof of Work). The RAFT consensus protocol is preferred for the initial phase; however, other consensus protocols will later be tested. RAFT consensus protocol needs at least three nodes to action properly. More nodes will ensure more security and reliability.

A testing tool, which is named GoHammer is developed. There were already testing tools like Chainhammer, but it wasn't preferred because of its dependencies and outdated modules. GoHammer is developed as there was a need to see the performance affect of the further customizations. This test tool is used to verify the research environment with scalability, latency, performance tests. TPS (transaction per second), block size, and various system metrics like CPU usage, memory usage are measured. This tool can also generate enormous number of transactions so that the system metrics can be tracked under extreme conditions. The source codes this tool is shared with the GPL license at the project GitHub page[10].

A decentralized application called Scanner[11] was developed for the management and monitoring of the blockchain network. Authorized users can perform operations such as viewing, adding, validating, and invalidating nodes through the web interface of the Scanner. This web interface also allows monitoring the network such as the number of blocks and the number of available nodes. The web interface of the Scanner is shown in Figure 7

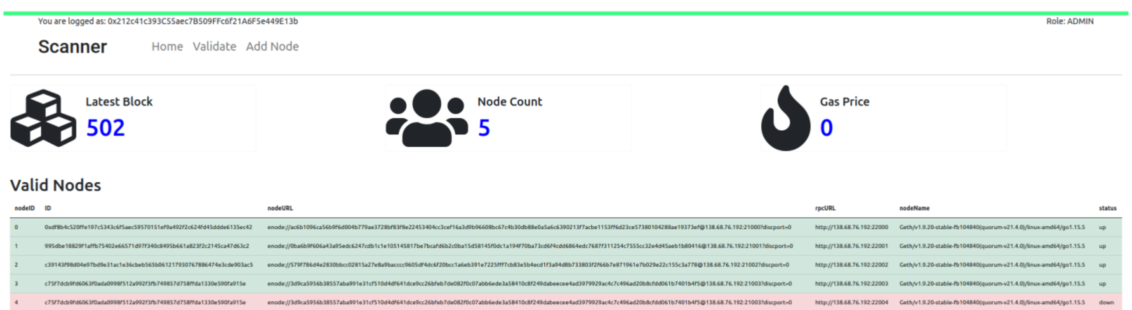

Figure 7. Scanner web interface.

Smart contracts are developed to autonomously manage the network. Our application has a TPer value, which defines the time value of periodic checks. This application periodically checks the activity status and TPS values of the nodes. A notification e-mail is automatically sent to the predetermined node authority in case of inactivity or when the TPS limit is exceeded. The system also has a TMax value, which defines the maximum allowed time of unavailability. If the specified TMax value is exceeded, the node may be removed from the list.

5. Discussion and evaluation

We carried two types of experiment. The performance evaluation on low-cost devices, and then the node stability control is given.

[10]Gohammer (2021) Gohammer Project. Website https://github.com/chain-ex/service [[accessed 11 November 2021]
[11]Scanner (2021) Scanner Project. Website https://github.com/ds4h/scanner [accessed 11 November 2021]

5.1. Performance evaluation on low-cost devices

A test is run on the DS4H's nodes to observe TPS, block count, transaction count, and various system metrics using GoHammer. One of the nodes has two vCPU (3.0 GHz Intel Scalable Processor) and 8 GB memory. The test scenario is as follows: first, a method of a predefined smart contract is called on the three nodes to generate transactions and get the TPS of the system. This process is repeated 150 times. After that, the test is stopped for 5 s, then a method of a predefined smart contract is called 300 times on three nodes and 5 s timeout. And finally, we repeated the same process with the predefined smart contract 1000 times.

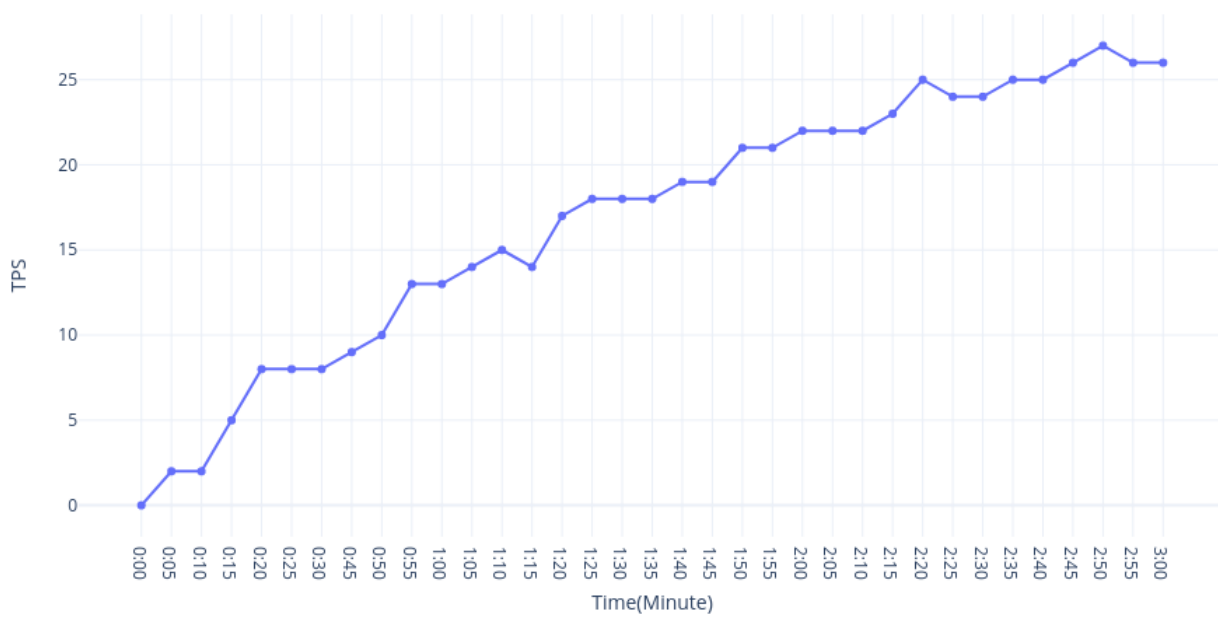

Figure 8. TPS by time.

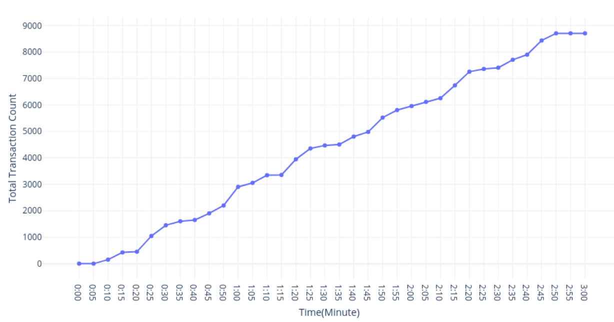

Figure 9. Comparison by transaction deployment time.

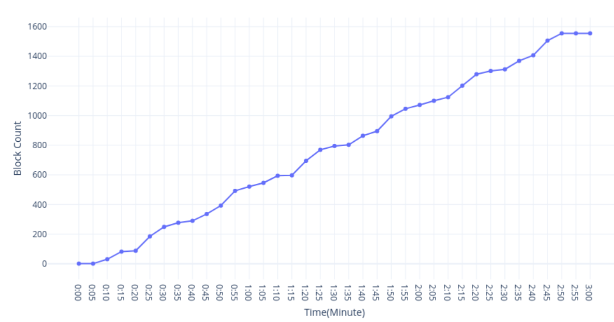

Figure 10. Block count by time.

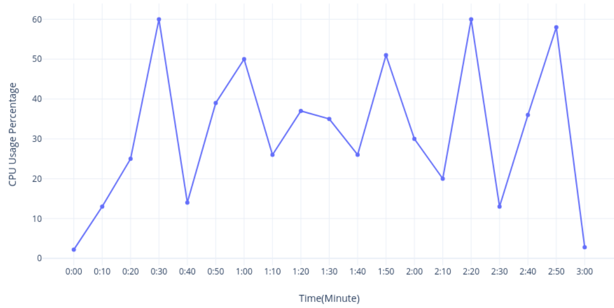

Figure 11. CPU usage by time.

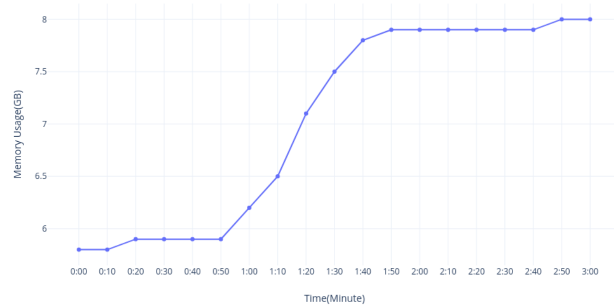

Figure 12. Memory usage by time.

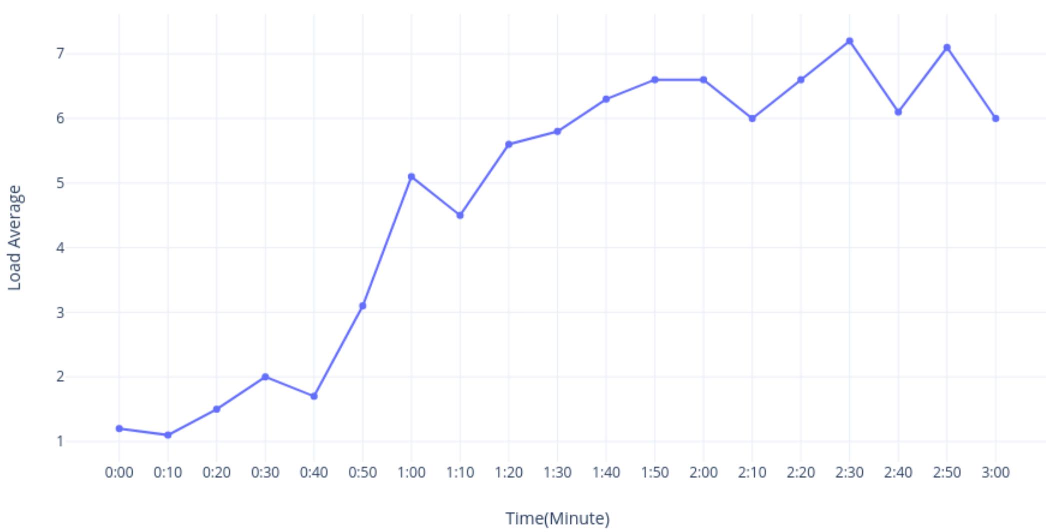

Figure 13. Load average by time.

We want to emphasize that this is not a stress test on Quorum. This test is implemented to show the performance analysis of low-cost devices on normal load. Total test execution time (without 5 s timeouts) is 1 min and 17 s approximately, and the best TPS was 26 transaction per second (Figure 8). The total transaction count is 8704 (is shown in Figure 9, and the total block count is 1555 (is shown in Figure 10). One of the nodes had a peak CPU usage at 60% during the test (is shown in Figure 11). In the test we have almost used all the available memory on the nodes, which are 8 GB (as seen Figure 12. The load averages of the system during the test can also be seen in Figure 13.

5.2. Decentralized governance test

The node stability control that is given in Algorithm1 is simulated as a decentralized governance test. A virtual machine (4 Intel vCPUs (2.5 GHz, 3.9 GHz turbo), 8 GB memory) is used from the Digital Ocean. We set up four IBFT nodes in the test scenario. GoHammer is used to create transactions on each node. We defined the system max TPS value as 100. The total value shows the total TPS in the network. The test lasted 60 s. Nodes send 40, 50, 60, and 70 TPS respectively. One of the nodes (Node3) starts to abuse the system by sending more TPS than the defined system max value. The Scanner detects this and blocks the node out of the system. The Figure 14 shows the network value return to normal values.

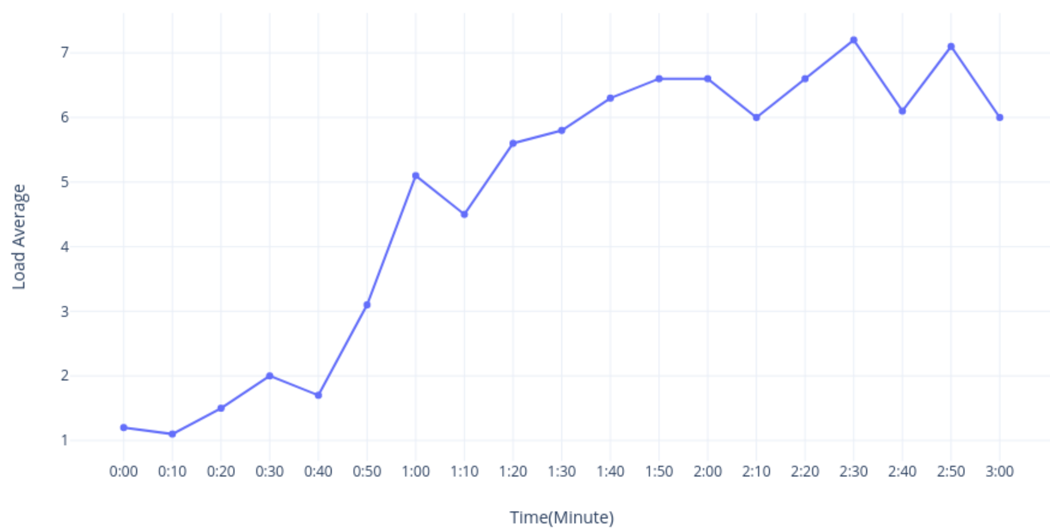

Figure 14. Decentralized governance test.

The scanner is effectively monitoring the network for node stability control. We are aware that blocking a node does not comply with the decentralized philosophy. However, such measures may be needed in a testbed to serve the resources to all of the researchers. A PoC (proof of concept) of such a process is given with this study.

6. Conclusion

A geographically distributed and decentralized academic testbed is deployed. “Decentralized Solutions for Humanity - DS4H” blockchain research network is installed and running with four nodes. The first DAPP running on this network; ”NGO Decentralized Resource Management System” won the 2nd prize in the TUBITAK 2242 (Research Project Competition for University Students), ”Information and Communication Technologies” category.

The prototype of a sustainable blockchain research system with decentralized management is deployed. Low-cost devices are used as partial nodes. Energy-efficient consensus protocols are used. We developed our tools (Chainex, GoHammer, Scanner) for blockchain research. Chainex enables developers to deploy smart contracts on the blockchain easily, and it is being used by our students already. It will help in developing more efficient decentralized systems. It will affect decreasing the costs of developing DAPP projects. A usage policy is prepared for the sustainability of this evolving network. Smart contracts are written to automize some management tasks. We started to develop our Gohammer benchmark tool and used it to test our blockchain network. The source codes of these tools are shared as open source.

We aim to make this network expand with possible new contributions from all over the world. We are also working on developing this system to support multiple blockchain networks. Future studies will include research on consensus protocols, new decentralized services such as decentralized DNS, and decentralized identity. IPFS (Interplanetary File System) will be integrated with the DAPPs.

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