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AN ELIXIR FOR BLOCKCHAIN SCALABILITY WITH CHANNEL BASED CLUSTERED SHARDING

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Abstract. Blockchain refers to distributed ledger technology which stores records without the help of a central authority. Born with bitcoin, this brainstorming technology finds its applications in healthcare, land registry, education, pharmaceutical industry, digital records, manufacturing companies and so on. The properties of blockchain such as immutability, distributed nature, tamper-resistant made it a disruptive technology in many applications. The highlighting feature of this pioneering technology is the distributed storage of ledger on all the nodes of the network. This helps to achieve decentralization without the trust for third party. The transactions are proposed, executed, validated and are then added as blocks to the blockchain. The problems with all the blockchain framework is scalability with respect to storage space and throughput. Scalability is the most significant factor to be considered in this big data era. This article proposes a solution called Channel Based Clustered Sharding (CBCS) approach for Hyperledger fabric blockchain framework. In this work, a lookup table is maintained which helps in forwarding the transactions to the clustered shards for validation. The CBCS approach helps in parallel transaction processing which in turn improves scalability and throughput of the system. The performance of the proposed work is measured with the help of Hyperledger caliper, a benchmarking tool for the performance analysis of Hyperledger fabric. The results show that the performance of the proposed system is increased from 3000 tps to 30,000 tps.

Key words: Blockchain, Sharding, Scalability, cluster, channel, Hyperledger fabric, Hyperledger caliper

1. Introduction.

1.1. Blockchain. Blockchain is a distributed ledger technology that stores records in a chained manner without the need for trusted central authority [1]. Blockchain, the underlying concept of Bitcoin gained its importance in the world of cryptocurrencies. Satoshi Nakamoto, the founder of bitcoin used Proof of Work consensus mechanism to make consensus among the participants [2]. The proof of work consensus involves high transaction fees and more computation time. Since the ledger must be stored on all the participants in the network, it takes more time for processing the transactions and adding the blocks to the blockchain [3, 4, 5]. This results in scalability issue in bitcoin blockchain which can process only 7 transactions per second. Several protocols have been proposed to solve this issue [6, 7, 8]. With the Proof of Stake consensus, Ethereum can process 27 transactions per second. The modular architecture and execute-order-validate mechanism of Hyperledger fabric framework makes it possible to transact 3000 transactions per second which is very low when comparing to visa which makes 7000 transactions per second [9, 10]. It is found that the root cause of scalability issues in blockchain is the way the ledger gets stored on the nodes and the amount of time taken by all the nodes for validating the transactions. If every node in the network validates the transaction, then it would result in more consumption of time, which in turn reduces the parallel transaction processing and scalability. This work proposes channel based clustered sharding method to improve the scalability factor of Hyperledger fabric framework. Hyperledger fabric, one of the key projects of IBM differ from other blockchain network in the way it is designed. It has modular architecture which allows the user to plug-and-play with its

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components and it uses execute-order-validate mechanism which helps to improve transaction throughput of the system [11]. It makes use of practical byzantine fault tolerant consensus mechanism which provides security to the system. The channel concept in Hyperledger Fabric play a significant role in providing privacy among the users of the system. In this work, Hyperledger fabric framework has been chosen to improve the scalability. The objective of this work is to increase parallel transaction processing and reduce transaction latency. Various solutions has been proposed by various researchers to improve the scalability of the system [12, 13, 14]. This article proposes a database mechanism called sharding which is used to cluster the nodes into shards in each channel. The blockchain Sharding mechanism profoundly improves validation time which in turn improves parallel transaction processing and thus scalability.

1.2. Sharding. Sharding is a database mechanism that helps to split and store the data in different resources. It helps to manage data faster and in an efficient manner. The database is divided into number of smaller pieces and each piece of data is stored on different servers and that server is responsible for storing and managing the data. A shard key is used to track which data has been stored on which server. Sharding concept was introduced in blockchain in the year 2017. Luu et al [15] in his paper published the use of sharding in blockchain in which each block in the blockchain is divided into sub blockchain and each sub-blockchain can store several collation packaged with transaction data [16]. These collation constitute the block in the main chain. This work reduces additional network confirmation which in turn increased the trading capacity of block by 100 times. Elastico and Zilliqa use sharding [17] and they prove that the probability that the attacker can control sharding is very negligible. In case of Ethereum, it is in the process of incorporating sharding mechanism in its network. It works in layer 2 for dividing the processing of large chunks of data across the network thereby reducing the network congestion and improving transaction throughput. In this work, sharding is proposed to validate the transactions based on the channels. For each channel, separate clusters of shards are presented which helps in validating the transaction data providing confidentiality and security. It also increases the parallel transaction processing of the system by reducing the overhead involved in validating the data on all nodes in each channel. The main contributions of this work are as follows:

1. To design a channel based clustered sharding approach for hyperledger fabric blockchain framework.
2. To analyse the performance of the system using hyperledger caliper benchmark tool in terms of success rate, throughput and latency.

Paper Organization: Section 2 discusses the background and related work. Section 3 proposes the CBCS approach for solving scalability problem. Section 4 evaluates the proposed work and presents the results. Section 5 concludes the paper and discusses the future work.

2. Background and Related Works. This work reviews two different kinds of solution to blockchain scalability issues. One is on-chain solutions and the other is off-chain solutions. On-chain solutions concentrate on block structure, algorithms for consensus, main-chain structure. Off-chain focuses on reducing the burden of on-chain transactions by executing some complex transactions off-chain.

2.1. On-chain Solutions. SEGWIT [18] proposed the segregated witness based solution for blockchain scalability issue. It redesigns the structure of the transaction by computing the transaction identifiers without including the count of signatures. Segwit acts as a soft fork and helps to create bigger block sizes which in turn increase the scalability of the bitcoin protocol. Han et al proposed the Consensus unit in which different nodes are organized as one unit and the data are stored in one node of a unit. This helps to reduce the duplication of data in all the nodes in the network. The storage space is greatly reduced, and the transaction throughput is increased [19]. In JIGSAW approach [20], each node in the network stores only transactions that are of more interest. Every node maintains a local storage in which all the relevant data transactions are stored locally without the intervention of other nodes in the network. This system verifies the validity of the transaction with the help of merkle branch information provided by the transaction proposer. This approach helps to reduce the storage space cost to 1.03% of the original cost of blockchain bitcoin system. LewenBerg in his work proposes a DAG based structure of blockchain that helps to improve the transaction rate of the network [21]. The DAG structure is created by referring multiple predecessors and accepting forgiving transactions. It increases the transaction volume of the network by propagating longer blocks in the network. This system avoids highly connected miners because of which the block creation time is greatly reduced and concludes that the scalability

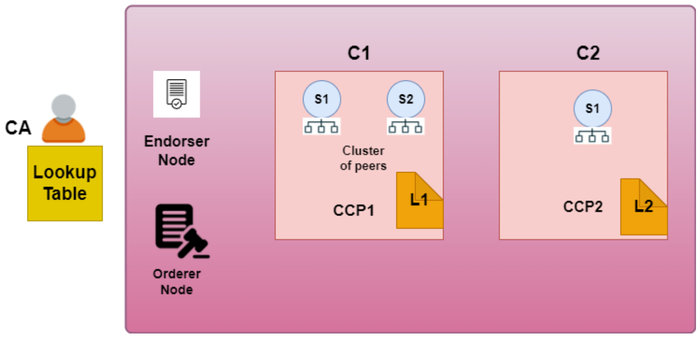

Fig. 3.1: Proposed System Architecture

of the system is greatly increased at the rate of security. [22] proposed a protocol called Phantom, based on Directed Acyclic Graph that supports faster and longer block generation. It overcome the security-scalability tradeoff using a greedy algorithm that helps to distinguish the blocks generated by honest nodes and blocks generated by non-cooperating nodes without following the mining protocol. This work guarantees liveness and fast confirmation times by the use of blockDAG.

2.2. Off-chain solutions. Poon J et al proposed a network of micropayment channels that enables bitcoin scalability. These micropayment channels are made off the chain and makes use of scripting opcodes that makes the transactions risk free and more scalable[23]. This work concludes that the bitcoin blockchain can scale upto millions of users without custodial risk or centralization. An off-chain blockchain transaction mechanism that creates long-lived channels for making arbitrary number of transactions between users in the network is presented in [24]. In this work, the payments are made between users without any confirmation delay. It guarantees end-to-end security between transactions in the bitcoin network. Sprites, a modular protocol approach that allows distrustful parties to make payments between them with reduced collateral cost is proposed by Miller et al. It makes use of generic state channel abstraction that helps to improve payment channel constructions and supports partial payments and withdrawal. Sprites ensures transaction scalability along with security in bitcoin network [25, 26]. HF-Audit, a decentralized data integrity auditing scheme based on Hyperledger Fabric is reported in [27]. In this work, bilinear pairing and commitments are made use of for improving the scalability and security of the Hyperledger fabric transactions at reduced cost. The security and scalability of HF-Audit is proved using Third-Party Audit selection algorithms based on complete and incomplete information. An adaptive framework that redesigns the consensus protocol of Hyperledger Fabric blockchain framework for improving the transaction throughput is proposed by Honar Pajooh. This framework checks the performance of Hyperledger fabric blockchain under various transaction workloads and different chaincode parameters. The impact on transaction latency and transaction throughput are studied and found that there is a significant improvement in the scalability of the system [28].

3. Proposed System Architecture. The proposed system architecture is depicted in the Fig. 3.1. It consists of peer nodes, endorser nodes, orderer nodes, channel 1, channel 2, certificate authority, channel configuration policy, shards C_1S_1, C_1S_2, C_2S_1, a lookup table and a ledger. The certificate authority in the Hyperledger fabric network is responsible for generating the certificates for the user. Using this certificate, the user can make transaction proposals and responses. The proposals from the user are signed with this certificate and are then transferred to the network. Along with this, in the proposed system the certificate authority is responsible for maintaining a look up table which helps the peer nodes to join the clustered shards and validate the transactions. The peer nodes are the nodes which is responsible for hosting the ledger data and the chaincode. The peer nodes are connected to the channels and each peer node stores the ledger data corresponding to the channels to which it is attached. The endorser nodes are the peer nodes which are responsible for endorsing the transactions proposed by the client applications. Only after every transaction gets endorsement according to the endorsement policies, the transactions be added to the blockchain. Orderer nodes are the special nodes in the Hyperledger fabric framework which helps in ordering the transactions into blocks. In our proposed system we assume that there are two channels. With the help of channels, the Hyperledger fabric framework provides privacy and confidentiality in transaction communications. The transactions between the participants of a channel are not visible to participants in the other channel. Each channel maintains a ledger which contains only the transactions happened between the participants of that channel. The channels are governed by the channel confirmation policies.

Ledger is the place where the transactions are stored. Ledger comprises blockchain and the world state. World state represents the current values of the data. World state contains the key value pair which stores the latest value for each key and also it contains the version number. The version number is used by the Hyperledger fabric internally and it changes after each update made on the world state value. Blockchain contain the transaction logs which resulted in the current value of the data. It stores the history of transactions and the blocks are linked to each other with the help of hash values.

3.1. Channel Based Clustered Sharding. The channel based clustered sharding approach has been designed for drug supply chain applications. The participants involved in this application are the manufacturer, retailer, wholesale, pharmacist and the consumer. The manufacturer purchases the raw material and produces the drug which is then sold to the retailer. The retailer purchases the drug and sell it to the wholesale. The wholesaler in turn sells the drugs to the pharmacist based on their request. The pharmacist can also purchase drugs from the manufacturer directly. This transaction between the manufacturer and the pharmacist must be kept private without the knowledge of other participants involved in the network. This is possible with the help of channels in the proposed system. The consumer purchases the drug from the pharmacist. The proposed architecture involves two channel. Each channel is responsible for maintaining its own ledger. Channel 1 is dedicated for the transactions that happen between the manufacturer, retailer, wholesaler and the pharmacist. Channel 2 is dedicated for the transactions that happen between the manufacturer and the pharmacist.

3.2. Shard Formation and Transaction Validation. Formation of shard plays a vital role in the proposed system. Each shard consists of a cluster of nodes in the network. The proposed CBCS consists of three shards namely C1S1, C1S2 and C2S1. When the nodes join the network, the nodes will be randomly assigned to one of the shards in each channel. With the increase in the number of peers, the number of shards will also increase. The shards are grouped in such a way that, they will validate the transactions only from certain nodes. In this work, shard C1S1 will validate the transactions from the manufacturer and the retailer nodes in channel 1. Shard C1S2 will validate the transaction from the wholesaler and the pharmacist node in channel 1. The shard C2S1 validate the transactions from the manufacturer and the pharmacist nodes in channel 2. This helps in parallel transaction validation which in turn increases the transaction throughput per second. Once the transactions are validated, they are then ordered and stored on to the blockchain.

3.3. Transaction Flow in the proposed system. The certificate authority is responsible for providing certificates to the nodes when they join the network. Using the certificate, the participants make transaction proposal in the system. This certificate also helps to verify the authenticity of the participants in the network. The certificate authority is also responsible for maintaining the look up table in which information about different shards and which nodes are present in which clustered shard are maintained.

When the retailer in channel 1 proposes a transaction tx, it is endorsed and the responses are sent back to the retailer. The transaction proposal and the response received are packed as a transaction and are sent to the orderer nodes. The orderer nodes arrange the transactions and propagate it to the nodes in shard C_1S_1. These nodes are responsible for validating the transaction and update the current status of the ledger. It is illustrated in Fig. 3.2. If any other transactions are received from the wholesaler in Channel 1 at the same time, then these transactions are validated by the nodes in shard C_1S_2. This helps to increase the parallel transaction processing of the system. The transactions generated in the channel 2 are validated by the nodes of the shard C_2S_1 and the ledger is then updated. If the transaction generated is a query transaction, then these transactions are not sent to the ordering node to be added to the blocks and for validation. This method helps in reducing the transaction processing time and improving the parallel processing of transactions. It also improves the scalability of the system to a larger extent.

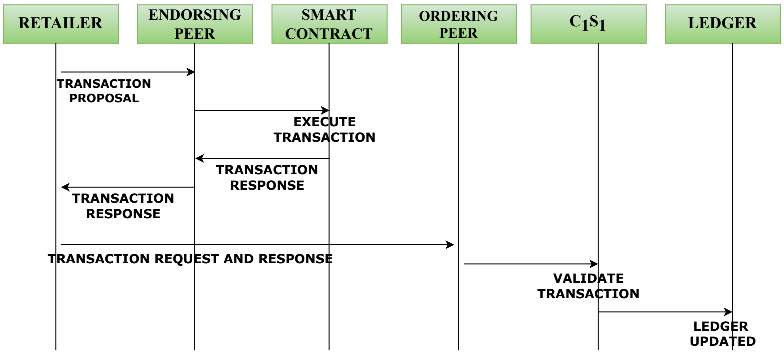

Fig. 3.2: Transaction Flow in the Proposed System

Transaction	Success Rate
1000	100
2000	100
3000	98
5000	96
10000	82
20000	75
30000	60
40000	54
50000	35

Table 4.1: Impact on Success Rate

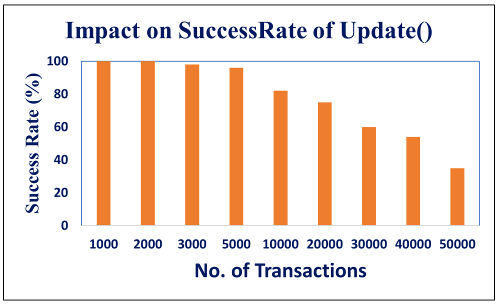

Figure 4.1: Impact on Success Rate of Update()

4. Result. The proposed system is tested with the help of a benchmarking tool called Hyperledger caliper. It supports Hyperledger fabric, Hyperledger sawtooth, Hyperledger besu and Ethereum blockchain framework. Hyperledger caliper produces results based on success rate, transaction throughput and transaction latency. The term success rate refers to number of successful transactions per test cycle.

The term transaction throughput is defined as the number of transactions that flow through the system per second. The term transaction latency is defined as the time interval between the transaction being completed and the response being available to the user application which created the transaction.

4.1. Setting up Hyperledger Caliper. To test the performance of the proposed work, certain parameters need to be set up in Hyperledger Caliper. The number of transactions, Rate control, Number of workers and Test rounds are the parameters set up in the experiment. The number of transactions has been kept increasing starting from 1000 to 50000. Throughout the experiment the rate control is set to be fixed, the number of workers are kept at 50 and the test is carried for update and query operations.

4.2. Impact on Success Rate. The experiment observed the impact on success rate for update and query operations and is depicted in Fig. 4.1 and Fig. 4.2. It is observed that the success rate for update operation is 100 percent for 1000 and 2000 transactions per second and it starts to decline as the number of transactions increased after 3000. It is also evident that the success rate of query operations does not get affected with the number of transactions.

4.3. Impact on Throughput. The impact on throughput on varying the number of transactions for update and query operations are calculated and are shown in Fig. 4.3 and Fig. 4.4. It is found that the throughput of the proposed system for 1000 transactions is 100 percent and the system is able to give above 90 percent for upto 30000 transactions in case of update operations. For query operations, it is found that the throughput is 100 percent for 1000, 2000, 3000 transactions. It is found to be above 90 percent for 5000, 10000 and 30000 transactions. It founds to decrease only after 40000 transactions.

Transaction	Success Rate of Query ()
1000	100
2000	100
3000	100
5000	100
10000	99
20000	97
30000	97
40000	95
50000	91

Table 4.2: Impact on Success Rate

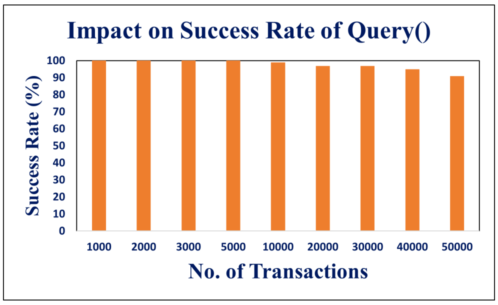

Figure 4.2: Impact on Success Rate of query()

Transaction	Throughput of Update ()
1000	100
2000	100
3000	98
5000	98
10000	94
20000	92
30000	90
40000	80
50000	65

Table 4.3: Impact on Throughput

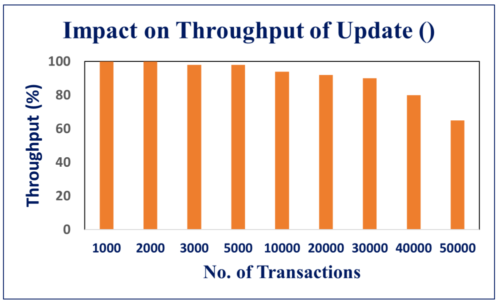

Figure 4.3: Impact on Throughput of update ()

Transaction	Throughput of Query ()
1000	100
2000	100
3000	100
5000	97
10000	96
20000	93
30000	91
40000	83
50000	80

Table 4.4: Impact on Throughput

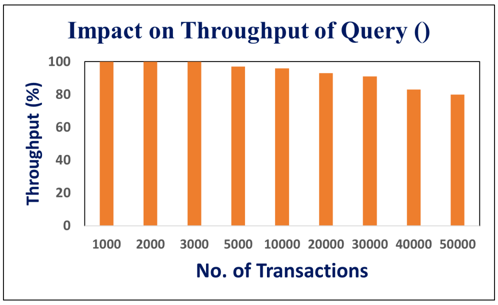

Figure 4.4: Impact on Throughput of query ()

Transaction	Latency of update()
1000	8
2000	16
3000	19
5000	21
10000	29
20000	34
30000	42
40000	70
50000	92

Table 4.5: Impact on Latency

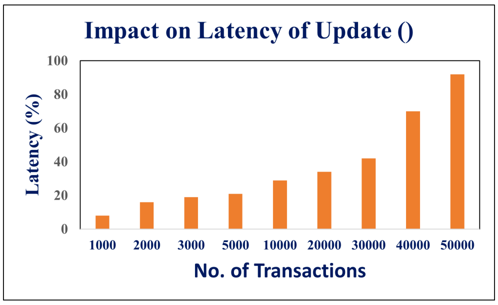

Figure 4.5: Impact on Latency of update ()

Transaction	Latency of query()
1000	3
2000	5
3000	12
5000	17
10000	21
20000	23
30000	28
40000	38
50000	43

Table 4.6: Impact on Latency

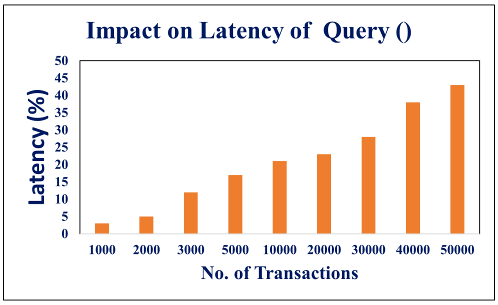

Figure 4.6: Impact on Latency of update ()

4.4. Impact on Latency. The latency for update and query transactions are observed and is found to be increasing in case of update transactions after 30000 transactions. It is also evident that the transaction latency is found to be high after 40000 transactions in case of query transactions. Fig. 4.5 and Fig. 4.6 illustrates the impact of number of transactions on latency in update () and query () operations.

5. Conclusion and Future Work. This work elaborates the significance of blockchain technology in various application areas. It envisions that blockchain stands as the one-stop solution for security and privacy issues. It also highlights that the blockchain technology inspite of its numerous advantages, suffers from scalability issue. This work proposed a channel based clustered sharding approach as the solution for scalability problem in blockchain. The system has been tested using the Hyperledger caliper, a blockchain benchmark tool for performance analysis of Hyperledger fabric framework. It is found that the proposed channel based clustered sharding system perform ten times faster than the system without sharding. It is also observed that the success rate and throughput begins to decrease and latency begins to increase once the system crossed 30000 transactions. It can be concluded that the channel based clustered sharding system performs ten times faster than the system without sharding. In the future, sharding can be used to store ledger data in the blockchain.

REFERENCES

[1] Jani, S, *The Emergence of Blockchain Technology & its Adoption in India.*,(2019)

[2] Nakamoto, S, *Bitcoin: A peer-to-peer electronic cash system. Decentralized business review*, (2008).

[3] Dannen, C, *Introducing Ethereum and solidity* , Berkeley: Apress, (Vol. 1, pp. 159-160). (2017).

[4] Sabry, S. S., Kaittan, N. M., & Majeed, I. , *The road to the blockchain technology: Concept and types.* , . Periodicals of Engineering and Natural Sciences., 7(4), 1821-1832. (2019).

[5] Akcora, C. G., Gel, Y. R., & Kantarcioglu, M. , LU-*Blockchain networks: Data structures of Bitcoin, Monero, Zcash, Ethereum, Ripple, and Iota*, Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery, 12(1), e1436.(2022).

[6] Rankhambe, B. P., & Khanuja, H. K. , *A comparative analysis of blockchain platforms–Bitcoin and Ethereum*, 5th international conference on computing, communication, control and automation (ICCUBEA) (pp. 1-7). IEEE., (2019)

[7] Padmavathi, U., & Rajagopalan, N, *Concept of blockchain technology and its emergence.* , In Research Anthology on Convergence of Blockchain, Internet of Things, and Security (pp. 21-36). IGI global.

[8] Yang, D., Long, C., Xu, H., & Peng, S, *A review on scalability of blockchain.* , Proceedings of the 2020 the 2nd International Conference on Blockchain Technology (pp. 1-6).(2020, March).

[9] Khan, D., Jung, L. T., & Hashmani, M. A. , *Systematic literature review of challenges in blockchain scalability*, Applied Sciences, 11(20), 9372. (2021)

[10] Nasir, Q., Qasse, I. A., Abu Talib, M., & Nassif, A. B. , *Performance analysis of hyperledger fabric platforms*, Security and Communication Networks, 2018.

[11] Amiri, M. J., Agrawal, D., & El Abbadi, A. , *On sharding permissioned blockchains.* , IEEE International Conference on Blockchain (Blockchain) (pp. 282-285). IEEE. (2019).

[12] Muthukumaran, V., V. Vinoth Kumar, Rose Bindu Joseph, Meram Munirathnam, I. S. Beschi, and V. R. Niveditha, *Efficient Authenticated Key Agreement Protocol for Cloud-Based Internet of Things*, In International Conference on Innovative Computing and Communications: Proceedings of ICICC 2022, Volume 3, pp. 365-373. Singapore: Springer Nature Singapore, 2022.

[13] Koti, Manjula Sanjay, V. Muthukumaran, A. Devi, V. Rajalakshmi, S. Satheesh Kumar, and V. Vinoth Kumar, *Efficient Deep Learning Techniques for Security and Privacy in Industry*, Cyber Security and Operations Management for Industry 4.0, October 27, 2022, 2–32.

[14] Kumar, Vinoth, V. R. Niveditha, V. Muthukumaran, S. Satheesh Kumar, Samyukta D. Kumta, and R. Murugesan, *A quantum technology-based lifi security using quantum key distribution*, In Handbook of Research on Innovations and Applications of AI, IoT, and Cognitive Technologies, pp. 104-116. IGI Global, 2021.

[15] Luu, L., Narayanan, V., Zheng, C., Baweja, K., Gilbert, S., & Saxena, P, *A secure sharding protocol for open blockchains.* , Proceedings of the 2016 ACM SIGSAC conference on computer and communications security (pp. 17-30).

[16] Zamani, M., Movahedi, M., & Raykova, M, *Rapidchain: Scaling blockchain via full sharding.* , In Proceedings of the 2018 ACM SIGSAC conference on computer and communications security (pp. 931-948).

[17] Aiyar, K., Halgamuge, M. N., & Mohammad, A. , *Probability distribution model to analyze the trade-off between scalability and security of shardingmbased blockchain networks.* , IEEE 18th Annual Consumer Communications & Networking Conference (CCNC) (pp. 1-6). IEEE. (2021).

[18] Kedziora, M., Pieprzka, D., Jozwiak, I., Liu, Y., & Song, H. , *Analysis of segregated witness implementation for increasing efficiency and security of the Bitcoin cryptocurrency*Journal of Information and Telecommunication, 7(1), 44-55.

[19] C.N.S.Vinoth Kumar, Vasim Babu M, Naresh R, Lakshmi Narayanan K, Bharathi V, , *Real Time Door Security System With Three Point Authentication",* , 4th International Conference on Recent Trends in Computer Science and Technology (ICRTCST), IEEE Explore, , May 2022. DOI: 10.1109/ICRTCST54752.2022.9782004.

[20] Xu, Z., Han, S., & Chen, L, CUB, a consensus unit-based storage scheme for blockchain system. IEEE 34th International Conference on Data Engineering (ICDE) (pp. 173-184). IEEE.(2018).

[21] Dai, X., Xiao, J., Yang, W., Wang, C., & Jin, H , *Jidar: A jigsaw-like data reduction approach without trust assumptions for bitcoin system*, IEEE 39th International Conference on Distributed Computing Systems (ICDCS) (pp. 1317-1326). IEEE. (2019).

[22] Lewenberg, Y., Sompolinsky, Y., & Zohar, A. , Inclusive block chain protocols. In Financial Cryptography and Data Security, 19th International Conference, FC 2015, San Juan, Puerto Rico, January 26-30, 2015, Revised Selected Papers 19 (pp. 528-547). Springer Berlin Heidelberg.(2015).

[23] Sompolinsky, Y., & Zohar, A, *Phantom. IACR Cryptology* , ePrint Archive, Report 2018/104.(2018).

[24] Poon, J., & Dryja, T. , *The bitcoin lightning network: Scalable off-chain instant payments.*, (2015).

[25] Decker, C., & Wattenhofer, R , *A fast and scalable payment network with bitcoin duplex micropayment channels.* , In Stabilization, Safety, and Security of Distributed Systems: 17th International Symposium, SSS 2015, Edmonton, AB, Canada, August 18-21, 2015, Proceedings 17 (pp. 3-18). Springer International Publishing.

[26] Miller, A., Bentov, I., Bakshi, S., Kumaresan, R., & McCorry, P. , *Sprites and state channels: Payment networks that go faster than lightning*, Financial Cryptography and Data Security: 23rd International Conference, FC 2019, Frigate Bay, St. Kitts and Nevis, February 18–22, 2019, Revised Selected Papers (pp. 508-526). Cham: Springer International Publishing. (2019).

[27] Lu, N., Zhang, Y., Shi, W., Kumari, S., & Choo, K. K. R. , *A secure and scalable data integrity auditing scheme based on hyperledger fabric*, Computers & Security, 92, 101741.(2020).

[28] Honar Pajooh, H., Rashid, M. A., Alam, F., & Demidenko, S. , *Experimental Performance Analysis of a Scalable Distributed Hyperledger Fabric for a Large-Scale IoT Testbed*, Sensors, 22(13), 4868. (2022)

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