electronics

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Performance Optimization of a Blockchain-Enabled Information and Data Exchange Platform for Smart Grids

Mubashar Amjad, Gareth Taylor *, Zhengwen Huang, Maozhen Li and Chun Sing Lai

Department of Electronic and Electrical Engineering, Brunel University London, Uxbridge UB8 3PH, UK
* Correspondence: gareth.taylor@brunel.ac.uk

Abstract: Exchanging information and data within smart grids is crucial to improve interoperability among system users. Traditional cloud-based data exchange schemes are centralized on a single trusted third-party platform. The schemes consequently suffer from single-point failure, a lack of data protection, and uncontrolled access. Blockchain enables data exchange in a decentralised and secure manner. A new platform is proposed in this work for exchanging data within smart grids using blockchain. It allows users to securely exchange data without losing ownership. This platform provides solutions to three critical problems: privacy, scalability, and user ownership. Particularly, the blockchain-based smart contract technology gives participants the programmability to access data. All interactions are authenticated and recorded by the other participants in the tamper-resistant blockchain network. Furthermore, the performance of the proposed blockchain platform is enhanced by integrating it with an artificial neural network (ANN). The proposed method is used to predict the network's throughput and latency, and the network administrator uses these predicted values to change the network's settings for a high throughput and low latency. Throughout the results, the proposed model achieves performance improvements in blockchain-enabled information and data exchange and adapts well to the dynamics of smart grids.

Keywords: information and data exchange; blockchain; optimization; Hyperledger Fabric; smart grids

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Citation: Amjad, M.; Taylor, G.; Huang, Z.; Li, M.; Lai, C.S. Performance Optimization of a Blockchain-Enabled Information and Data Exchange Platform for Smart Grids. *Electronics* **2023**, *12*, 1405. https://doi.org/10.3390/electronics12061405

Academic Editors: Oguzhan Ceylan, Murat Gol and Aydogan Ozdemir

Received: 25 January 2023
Revised: 1 March 2023
Accepted: 10 March 2023
Published: 15 March 2023

1. Introduction

The amount and frequency of data exchange, as well as the services that transmission system operators (TSOs) obtain through resources connected to distribution, are constantly rising [1–3]. To ensure that these services are utilized effectively and efficiently throughout the system, increased collaboration between TSOs and DSOs is necessary to facilitate the sharing of information and data [4]. The enhanced communication and information exchange between TSOs and DSOs allow for the transmission and distribution networks to be jointly operated and planned [5,6]. This will also pave the way for the entry of new market actors and the implementation of innovative business models. It is normal practice in today's world for TSOs and DSOs to share information and data with one another. Despite this, there is a great need to considerably improve the levels of information and data sharing in order to raise the degree of overall system interoperability [7]. The actions of one operator can have a significant impact on other system operators, which is a growing concern. With the shift from traditional generation methods to renewable energy sources in transmission and distribution, the overall control over generation has diminished. The exchange of information and data using cloud computing platforms is one of the most promising future study areas for smart grids [8]. In addition, the proposed method makes use of cloud computing in order to simplify the process of exchanging critical information and data between TSOs and DSOs. TSOs and DSOs are increasingly recognizing the need to enhance observability levels on each other's systems.

1.1. Background and Motivation

Numerous advancements have been made in the field of cloud computing for smart grids, with a lot of effort being made in this direction. The approach to exchange data between TSOs and DSOs via a cloud platform was proposed by Radi et al. [9], which allows DSOs to use their resources to balance power systems. The primary cause of power flow constraints in distribution and transmission networks is an excess of intermittent RES. In the future, it will be necessary to address these operational limitations in a manner that is more coordinated, more productive, and cost-effective [10]. If TSOs and DSOs want to collaborate effectively and improve their coordination, having an infrastructure for information and communication technology (ICT) is essential [11].

Data exchange is crucial for the efficient and reliable operation of smart grids. Smart grid technologies enable the real-time monitoring and control of power systems, enabling the integration of renewable energy sources (RES) and the management of distributed energy resources. Data exchange enables two-way communication between utility companies and consumers, which allows for a more efficient management of the demand and supply of electricity. This can help to reduce costs, improve reliability, and increase the penetration of RES. There are several current limitations for exchanging data within smart grids using ICT. Some of these limitations include data privacy, security, interoperability, and data storage and management. In this paper, our goal is to address the limitations outlined above by presenting a proposed solution through our approach.

1.2. Literature Review

Blockchain technology has been applied to many fields, and smart grids are one of them [12]. Blockchain has the potential to establish a trading infrastructure within smart grids. Using blockchain, users would be able to trade electricity with one another without relying on a third party. The benefits of a real-time market, simplified trading structures, and improved user anonymity in smart grids should all be taken into account [12]. In order to overcome the issue of interoperability, blockchain may be used for activities other than the construction of a trade infrastructure. For example, it may be used to facilitate the transfer of information and data within smart grids.

Blockchain can also aid in the integration of energy production, transportation, consumption, and storage [13]. Renet et al. [14] showed how to authenticate carbon emission rights, protect cyber-physical systems, trade virtual power resources, and coordinate multiple energy systems. A central operator may still be needed to build trust in direct consumer-to-consumer transactions [15]. Smart contracts take care of payments automatically, and blockchain keeps track of the information from smart meters and transactions. Wu et al. [16] proposed a hybrid blockchain platform to increase internet efficiency, decentralize oversight, and offer secure data storage. Decentralized energy trade was proposed by Oh et al. [17] using blockchain technology.

Smart grid systems are created to simplify the process of producing and consuming local energy for prosumers and consumers [18]. Increased local energy production and consumption can help to reduce transmission losses. Electricity should be traded between users and consumers on a peer-to-peer basis. Centralized transaction management between smart grid users and consumers will be prohibitively expensive and require a complicated communication infrastructure [19]. Consequently, a decentralised method is favoured [20]. In addition, as the number of stakeholders increases, it will be hard to manage a large amount of data from a single location. This necessitates that the central node be able to rapidly analyse large amounts of data, making it more susceptible to failures.

The technologies of blockchain and big data have been integrated for use in a variety of applications of smart grids. Blockchain can be used in big data systems for various purposes, such as decentralized private data management, connectivity to the Internet of Things, the resolution of disputes over digital property, and adoption by government bodies [11]. To fortify the safety of big data platforms, Pothumani et al. [21] described a blockchain-based access control architecture. However, when the framework used blockchain technology for access control, it uncovered several critical problems. Uchibeke et al. [22] proposed a blockchain access control ecosystem that would make it easier to control access to large data sets and stop data breaches at the same time. As evidenced by the research [13,23], distributed ledger systems have thus attracted interest in a variety of energy-related applications, with an emphasis on energy trading and markets. In this context, peer-to-peer trading through microgrid energy markets is a hotly debated subject. Small-scale users and producers can trade locally produced energy inside their communities thanks to microgrid energy markets. As a result, it is suggested that the consumption of energy should be close to where it is produced, fostering sustainability and the effective utilization of local resources.

Liu et al. [24] proposed a permissioned blockchain that provides a peer-to-peer energy trading network using Hyperledger Fabric. Energy nodes, energy aggregators, and smart energy meters are the three components of the model used by the authors. These nodes can either be sellers or purchasers, depending on the overall energy situation. The energy aggregator, which can also act as a data repository, handles all activities associated with trade. Each node's smart energy meter tracks and totals energy flows in real-time. To achieve local balance in renewable energy generation, Xie et al. [25] presented a conceptual framework based on blockchain that enables houses to exchange energy with one another without the interference of utility providers. In addition to ensuring a secure, dependable, distributed storage of data pertaining to transactions involving renewable energy, the results reveal that this method also facilitates the automatic settlement of transaction outcomes. Several researchers [26–28] have discussed the possibility of integrating Hadoop [29] with blockchain. The main objective of using Hadoop is to speed up the processing of large amounts of data.

1.3. Main Contributions

The key contributions of the papers are as follows:

- A novel approach for information and data exchange between entities in smart grids using blockchain.
- The use of off-chain storage for data using the Hadoop Distributed File System, built on top of a permissioned blockchain.
- The confidentiality and ownership of data by executing third-party computing within the data owner's environment. This feature makes it well-suited for smart grid entities such as TSOs and DSOs.
- Improving the performance of our blockchain platform, using an optimization technique based on ANN. The proposed system is built using a modular and extensible architecture, which allows for interaction with various external machine-learning modules.
- Validation and testing through a case study involving data exchange between smart grid entities, using a case study that was an output of a major EU-funded Horizon 2020 research project TDX-ASSIST [30].

1.4. Paper Structure

The paper is organized as follows. Section 2 explains the fundamental concepts of blockchain and big data technology used in this research. Section 3 presents a brief introduction to the proposed data exchange architecture. Section 4 details the conceptual architecture of the proposed optimization technique, including a description of the use case. Section 5 presents the experimental implementation and results.

2. Basic Concept of Technology Used

This section provides an overview of blockchain technology and covers some fundamental concepts related to blockchain technology and big data systems.

2.1. Blockchain Technology

A blockchain is a type of distributed database that keeps a ledger that is encrypted. The name comes from how it is put together. In the blockchain, each block comprises of multiple transactions, and whenever a new transaction takes place, a record of that transaction is added to the ledger of all participants. Most people use Bitcoin and Ethereum as their blockchain platforms. When using blockchain, all of the transactions are put into a single block and saved for good. A blockchain is made by linking these blocks in order and in a straight line. A hash of the block header is used to find each block in the blockchain. New blocks can be added to the blockchain by tracing the history of valid network transactions back to the first block [31]. The structure of a blockchain is presented in Figure 1.

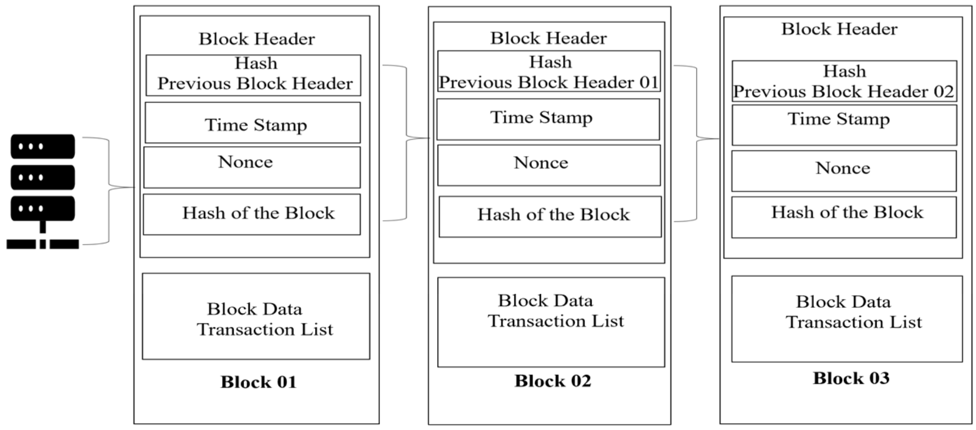


Figure 1. Blockchain block structure.

Blockchain technology can be classified into two types: public and private [32]. In a public blockchain, participants are anonymous, and the verification process is open to anyone who wants to join the network. Examples of public blockchains include Bitcoin and Ethereum [31]. On the other hand, a private blockchain network is managed by a central authority that grants permission to users to join. The verification process is controlled by a consortium, which has the final say on which nodes are allowed to participate. As a decentralized ledger, any participating node in the blockchain can verify the validity of a transaction. These nodes collect a batch of transactions and append them to the existing ledger. As the network grows, more and more nodes can contribute to the blockchain simultaneously. To resolve this issue, nodes need to reach a consensus on which node will append the new block, and this process is called consensus agreement.

- Hyperledger Fabric (HLF): Hyperledger Fabric is a private blockchain solution that is tailored for enterprise use. It requires user identification and is only accessible to its members. Unlike public blockchains such as Ethereum and Bitcoin, it does not use cryptocurrency, and access is restricted. Joining the network requires registration and authentication. Hyperledger Fabric uses the practical Byzantine Fault Tolerance (PBFT) algorithm to validate transactions and construct blocks. It is composed of various components such as peer nodes, ordering service nodes, and clients from different organizations. Each of these components has a network identifier provided by a Membership Service Provider (MSP), which is typically associated with an organization [33]. In Hyperledger Fabric, the identities of all organizations are transparent and verifiable by all network participants. It also includes a built-in chain code that can be utilized by other applications to interact with the ledger [24]. The chain code mostly interacts with the global state rather than the transaction log. The programming languages Go or Node.js can be used to create the chain code.
- Smart Contracts and Consensus Algorithm: One of the key features of blockchain technology is the use of smart contracts. Smart contracts were first introduced by Nick

Szabo as a way to digitally facilitate, verify, and enforce the negotiation or performance of a contract [32]. Any kind of decentralized computer software that operates without a third party is a smart contract on the blockchain. A blockchain transaction can only occur when the conditions specified in the smart contract are met. Public blockchains, such as Bitcoin and Ethereum, are anonymous, allowing anyone to create smart contracts that require a significant amount of computational power. All network users participate in the proof of work (PoW) consensus process, which can lead to significant delays if a smart contract takes a long time to execute or contains an infinite loop. This can also make the network vulnerable to denial-of-service (DoS) attacks. To address this issue, Ethereum introduced the concept of "gas" to link the cost of smart contract execution to financial considerations [34].

Hyperledger utilizes the PBFT consensus mechanism, which can handle up to a third of malicious byzantine replicas. A client initiates a ledger update by transmitting a transaction to its associated endorsers. In order for the proposed transaction to be approved, consensus on the proposed ledger update is required between all endorsers. The client individually requests approval from each endorser. Once approval is obtained, the transaction is sent to connected orderers to establish consensus. Afterwards, the transaction is transmitted to peers responsible for maintaining the ledger to be committed.

2.2. Big Data Systems

Big data is defined as a set of information that cannot be effectively understood, gathered, handled, or processed using conventional techniques [29]. Big data has four main traits: quantity, variety, speed, and authenticity. These characteristics display the amount of generated and stored data as well as its type, speed of generation and processing, quality, and value [35]. For large data analytics, some of the most well-liked frameworks are Hadoop [35], Spark3, MongoDB4, Strom5, Cassandra6, Neo4j7, and others. Hadoop is a well-known open-source framework that can be used both on your own computer and in the cloud.

A distributed computer cluster system called Hadoop is used to manage big data sets. MapReduce is a programming paradigm that forms the foundation of the open-source Hadoop platform. The two components of Hadoop have distributed processing, known as MapReduce and the Hadoop Distributed File System (HDFS) [29]. Using common hardware, HDFS is a distributed file system. It is similar to other distributed file systems in many ways. Despite this, it stands out from other distributed file systems since it is built to run on low-cost hardware and is incredibly fault-tolerant. For applications that require speedy access to large data sets, there is a file system called HDFS [36]. Master and slave nodes make up HDFS's architecture. Data nodes, typically one for each node in the cluster, manage the storage devices associated with the nodes on which they execute. HDFS is built for storing massive files reliably over a large cluster of machines. Every file is organised as a series of blocks, each with the same size except for the last one, whose size can vary. To ensure data integrity, files contain redundant blocks. Each file has its own settings for the block size and replication factor. The number of copies of a file is configurable in the software. The files' replication factors can be set at creation time or modified later. One person can edit a write-once HDFS file at a time.

3. System Model Design

This section illustrates the system design that allows the exchange and sharing of data within the entities of the smart grids. This solution combines blockchain technology with HDFS for off-chain storage.

This paper presents a new architecture for smart grids information and data exchange by integrating Hyperledger Fabric (HLF) blockchain with Apache Hadoop. By executing third-party computing within the data owner's environment, the proposed architecture ensures the confidentiality and security of the data. Organizations in the electricity grid, such as TSOs and DSOs, can benefit from this platform. The use of blockchain technology and smart contracts allows for transparency in data access and exchange, enabling users to track who accessed their data, when and for what purpose.

Data producers: TSOs, DSOs, and other market participants are the data producers in this exchange platform. Participants on the network contribute to generating data. This data can be uploaded to a cloud server and blockchain network for storage or retrieved and shared with other participants on the network.

Exchange Platform: Information collected by different smart grid entities are stored on cloud servers. The blockchain is used to maintain the index record of data, which may include information about the location of data storage. This serves as an off-chain data storage solution for the network.

Data consumers: Data consumers are the network that also needs to be registered with the regulators. The data is available to data consumers based on whether the request is accepted or not.

Figure 2 represents the registration process of the system participants involved in the proposed platform [37].

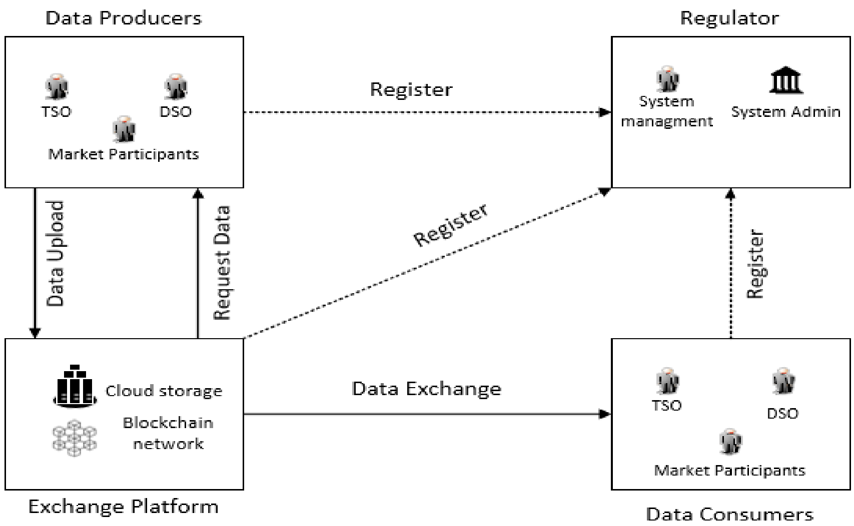


Figure 2. System participants.

The architecture for exchanging information and data within smart grids is represented in Figure 3 [38]. It is composed of three components: data storage, blockchain, and computation. The blockchain consortium's primary users are data producers and consumers, TSOs, DSOs, and market participants. The user enters data, which are then sent to Hadoop for processing using blockchain. Only data consumers who have been authorised by the system will be able to run their code using the provided data set. The smart contract that analyses the client's code is deployed by the data supplier. By monitoring potentially harmful features in user code, the smart contract limits computational complexity. The smart contract was jointly developed by the data providers. Included in the design is the HDFS storage layer, which is responsible for archiving information. To improve performance, the suggested method moves data storage away from the blockchain and onto an off-chain database. As the blockchain accumulates less data, it becomes more computationally efficient.

The HLF blockchain's public ledger has a limited capacity for data storage. As the size of the distributed ledger used by the blockchain platform increases, the performance of the HLF degrades. In the proposed method, a distributed ledger is used to track the origin of data. To address this limitation, data are moved into the Hadoop ecosystem for off-chain storage. Data integrity is verified using checksums and confirmed through comparison with information recorded in the distributed ledger and information stored in the Hadoop database. HLF has implemented a chain code to streamline these procedures at each peer node, and a built-in client library is used to transmit the data checksum and provenance information. This eliminates the need for file storage operators. In contrast to storing data on the blockchain, Hadoop allows for faster data processing, and the blockchain is used to confirm the accuracy of the data. The data's location and address can be retrieved from the ledger, and the Hadoop data warehouse can be queried for the information.

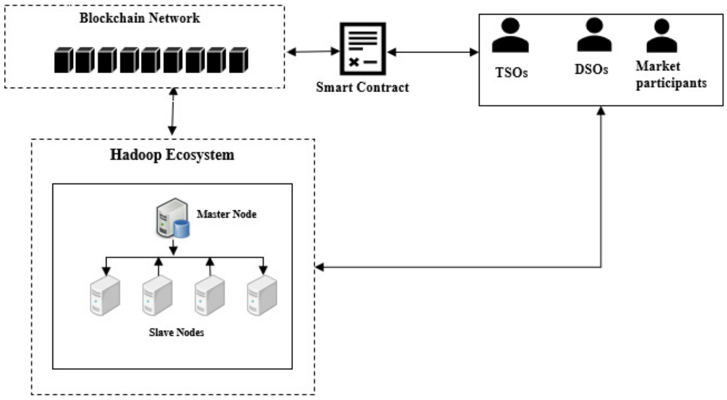


Figure 3. Architectural design of the blockchain-based approach for data exchange.

When a user makes a request for information to the data provider, the request is evaluated to determine if the user has the appropriate permissions. If the request is granted, the smart contract will perform certain preliminary checks. Upon passing these checks, the data are then delivered to the user. The proposed framework enables entities within the smart grids to exchange data while maintaining data security.

4. Overview of the Conceptual System Architecture

This section explains the performance optimization of the proposed blockchain network using ANN. The conceptual architecture of the ANN-based performance optimization is shown in Figure 4. The blockchain network is composed of multiple nodes that act as hosts for smart contracts and store copies of the distributed ledger to maintain network stability. The ANN-based prediction module is external and can be connected to the blockchain network. By utilizing the functions specified in the smart contract, network users can submit transactions. The network's benchmark results are monitored in real time, and these values are passed to the smart contract. The ANN module is implemented to enhance the performance of the blockchain network. The consensus is reached across the entire network and the execution results are returned to the user. The predicted throughput values persist in the predicted result DB. These values are passed to the network administrator after each test to change the network configuration based on the predicted throughput and latency. Once optimal conditions are met, the test is stopped.

4.1. Artificial Neural Network (ANN)

An ANN is a computational model that mimics the structure and function of the human brain. It consists of multiple interconnected processing units, known as neurons, that work together to solve a given problem [39]. An ANN is built with weighted directed graphs as its architecture, where artificial neurons are represented as nodes, and the directed arrows and weights depict the relationship between the neurons' outputs and inputs. ANNs can be classified into two types based on their architecture: feed-forward networks and recurrent networks. In this paper, a feed-forward ANN is used due to its high potential. To identify the best ANN training module, various configurations are experimented with, such as adjusting the number of neurons in the hidden layer, the learning rate, and the activation function. Multiple rounds of experiments were conducted for each training network configuration, with the average results recorded for later analysis of the random factor used to initialize the ANN network weights. The detailed structure of the learn-to-predict ANN model is presented in Figure 5 [39].

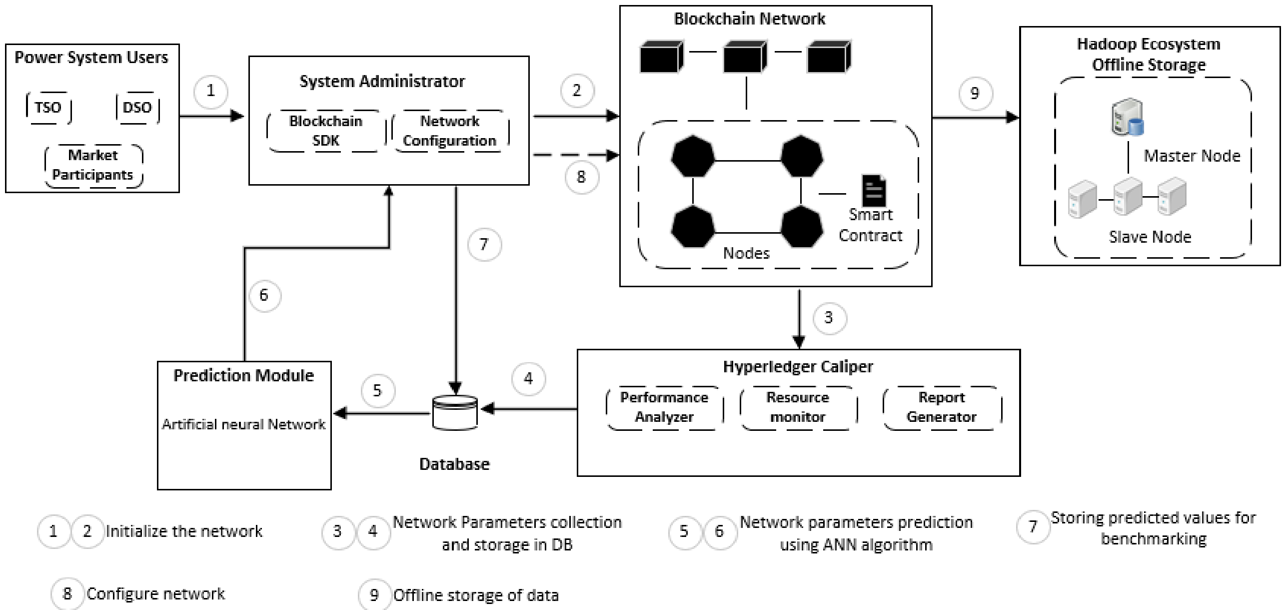


Figure 4. The architecture of the ANN-based performance optimization of blockchain.

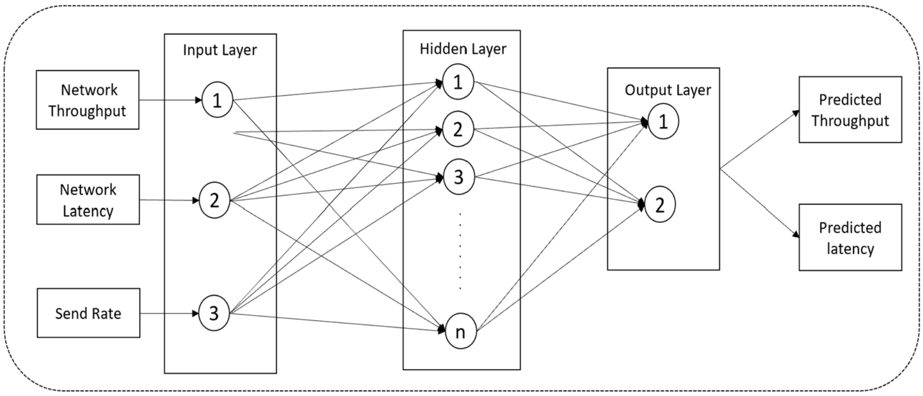


Figure 5. The detailed structure of the learn-to-predict ANN model.

The process of performance optimization using an ANN begins by importing the data and performing initial preprocessing, which includes checking for missing values and providing a data description. Labels are then assigned as optimal and non-optimal classes. Before being fed into the network, the data are segmented into three categories: 15% for validation, 70% for training, and 15% for testing. The training network configuration is set up with three inputs, 20 neurons in the hidden layer, and two outputs. The optimization module is executed repeatedly by analysing benchmark results to find the optimal solution for the network. These results are then provided to the system administrator to update the system configurations based on the predicted throughput and latency. The learn-to-predict model is executed outside of the blockchain network. The mathematical formula for an artificial neural network (ANN) to learn to predict is presented in Equation (1). The formula can be described as a function that takes input data and applies a series of weighted computations and activations through the network's layers to produce an output. With an input vector of x, the output of an ANN can be expressed mathematically as:

$$y = f(Wn * f(Wn - 1 * \ldots\ f(W1 * x + b1) \ldots\ + bn - 1) + bn) \tag{1}$$

where f is the activation function, Wn, Wn − 1, . . . , W1 are weight matrices, b1, . . . , bn are bias vectors, and n is the number of layers in the network.

4.2. Use Case Implementation

The use case presented in this paper focuses on a specific data exchange method between the TSO and DSO. The service provided by this BUC is the coordination of long-term network development plans between the TSO and DSO at the TSO/DSO interface, including the development plans for the smart grids [39]. Effective communication and information sharing between TSOs and DSOs are vital for the development of long-term plans for network expansion and reinforcement. These plans are essential for maintaining the reliability and availability of the grid over time. The current simplifications in network models may be improved in the future as TSOs and DSOs discuss and agree on changes. These changes may include the addition or removal of interface substations and high-voltage power lines, as well as plans for network reinforcement by the TSO or DSO. The connectivity of key grid users to the TSO or DSO network may also be included in these plans. When changes are made to the TSO/DSO interface plan, this information is typically shared between both parties. By considering both the TSO and DSO network plans, opportunities for optimization and synergy can be identified, and the best time for implementation can be determined.

Figure 6 illustrates the platform's operation in the scenario of development plans. The process involves four steps in which the DSO and TSO use the platform to share information, such as plans for building transmission networks and plans for building distribution networks. Table 1 provides a step-by-step analysis of the use case.

Figure 6. Use case mechanism.

Table 1. Comparison table of some key features between blockchain and conventional platforms.

Features	Blockchain Platform	Conventional Platform
Data Storage	Decentralized	Centralized
Data Access	Permissioned/Public	Centralized
Consensus Mechanism	Distributed Consensus	Centralized Decision Making
Transparency	Visible	Limited visibility
Scalability	Limited	More Scalable
Trust	Based on Consensus	Centralized

5. Experimental Setting

In this section, comprehensive experiments are conducted using the proposed optimization technique on our blockchain-enabled data exchange platform. The results of the baseline scheme and our scheme are obtained and compared.

5.1. Environment Development

Table 2 presents the tools used to build the proposed architecture. Hyperledger Fabric was used as the blockchain framework and was installed on the Linux operating system. The Docker engine was used to create virtual machines on which each Hyperledger Fabric was embedded in a Docker image. Additionally, Hyperledger Caliper was integrated into the blockchain network to collect information about the network. An ANN was used as a learn-to-predict module to predict transaction throughput and latency to find optimal configurations for the network. The HDFS was used for the off-chain storage of information and data exchange for better performance. A non-relational database, MongoDB, was utilized to store the benchmark results from Hyperledger Fabric for the prediction module.

These tools and technologies were integrated to enhance the performance of the proposed blockchain-based data exchange platform for smart grid entities.

Table 2. Step-by-step procedure of use case scenario.

Step	Information Producer	Information Receiver	Method/Information Exchanged	Information Format	Access Control	Time Scale
1	DSO		Development plans for transmission network	XML	upload, display, delete	years
2		TSO	Development plans for transmission network	XML	download, display, delete	years
3	DSO		Development plans for the distribution network	XML	upload, display, delete	years
4		TSO	Development plans for the distribution network	XML	download, display, delete	years

5.2. Performance Evaluation

The proposed blockchain framework was evaluated using Hyperledger Caliper, an open-source tool. The evaluation focused on measuring the network's throughput and latency. Table 3 presents the components used in the development of the proposed platform. The configuration parameters used in the proposed framework are listed in Table 4. These parameters were adjusted to enhance the performance of the blockchain network.

Table 3. Development environment of the proposed framework.

Components	Specification
Docker Engine	20.10.17
Docker Composer	1.29.2
CPU	Intel Core i7-3.00 GHz
Memory	16 GB
Operating System	Ubuntu 20.04
Node SDK	Node.js
Blockchain Platform	Hyperledger Fabric
Programming language	JavaScript
DBM	MongoDB

Table 4. Experimental setup parameters for a blockchain configuration.

Parameters	Values	Description
Block Size	128,512 KB	Maximum size per block
Block Interval	250,300,350	Time to create a new block
TSOs	1	Transmission system operator in the network
DSOs	5	Distribution system operator in the network
Internal Database	CouchDB	Ledger data storage
External Database	HDFS	Off-chain data storage
Ordering Service	PBFT	Orders transaction into the block
Endorsing Policy	Raft	Specifies the policy that members must agree on before a new block is added

The participants of the network were TSOs and DSOs. In this experimental setup, one TSO and increasing number of DSO up to five were used. Users who can submitted a transaction to the blockchain network were considered participants. A simple smart contract was used to evaluate the blockchain network's backend features. Every 250 milliseconds, a new block was created, and each block could hold up to 50 transactions by default. Raft was the service of choice for ordering by default, although it only has a single ordering node. The default state database was CouchDB. The experimental findings provided here were averaged over several rounds to mitigate the impact of rounding mistakes due to network congestion.

The proposed blockchain platform's performance was evaluated using network throughput and latency as the key metrics. The transaction throughput, measured in transactions per second (TPS), represented the number of total successful transactions (TST) executed during a specific period of time (t). Transaction per second was measured across all the nodes of the blockchain network. Equation (1) specifies how tps was calculated.

$$\mathrm{TPS} = \frac{\mathrm{TST}}{\mathrm{t(s)}} \tag{2}$$

Furthermore, Equation (2) [35] specifies how to calculate the read rate (RR) and write rate (WR) per second in relation to the total number of read and write transactions (R/W Tt) performed.

$$\mathrm{RR/WR} = \frac{\mathrm{R/W\ Tt}}{\mathrm{t(s)}} \tag{3}$$

Likewise, the proposed framework was also evaluated based on latency, read/write latency and network transaction latency. The read/write latency (R/W L) is a measure of the total time it takes from when a request is sent, which is the request time (Rt), to when a response is received (Rtr). Equation (3) specifies how read/write latency was calculated.

$$\mathrm{R/W\ L} = \mathrm{Rtr} - \mathrm{Rt} \tag{4}$$

Network latency is a measure of the total time it takes for a transaction to be validated and approved on the blockchain network. This time included the time taken for the nodes to reach a consensus, which is called the committing time (Ct). Equation (4) specifies how transaction latency (TL) was calculated.

$$\mathrm{TL} = \mathrm{Ct} - \mathrm{Rt} \tag{5}$$

5.3. Experimental Results

In this section, the effectiveness of the proposed method in optimizing the blockchain network is verified by comparing it with the baseline scheme. The evaluation results of the learn-to-predict method compared to the baseline network are presented using sample data. To evaluate network transaction throughput, Figure 7a,b compares the network throughput and latency respectively of the proposed blockchain performance improvement mechanism based on learn-to-predict with the baseline network, at varying transaction send rates between 30 and 400 tps. The transaction throughput rose exponentially with the sending rate until it reached about 210 tps. As soon as the send rate hit this limit, the rise of transaction throughput slowed down and started to level out. This is because the network exceeded the processing capacity, resulting in a backlog of unconfirmed transactions. Limited block size and high block creation times are the reasons for these saturation on the blockchain network. The network transaction throughput increased by 23.9% to 153.2 tps and 201.4 tps, respectively, when the send rate was raised to 175 tps.

Figure 7b compares the network latency using the proposed mechanism based on learn-to-predict with the baseline network over different transaction send rates to evaluate transaction latency with one TSO and one DSO (ranging from 30 to 400 tps). The transaction latency of the learn-to-predict mechanism and the baseline were 77 ms and 102 ms. With a send rate of 400 tps, the transaction latency was reduced by 21%.

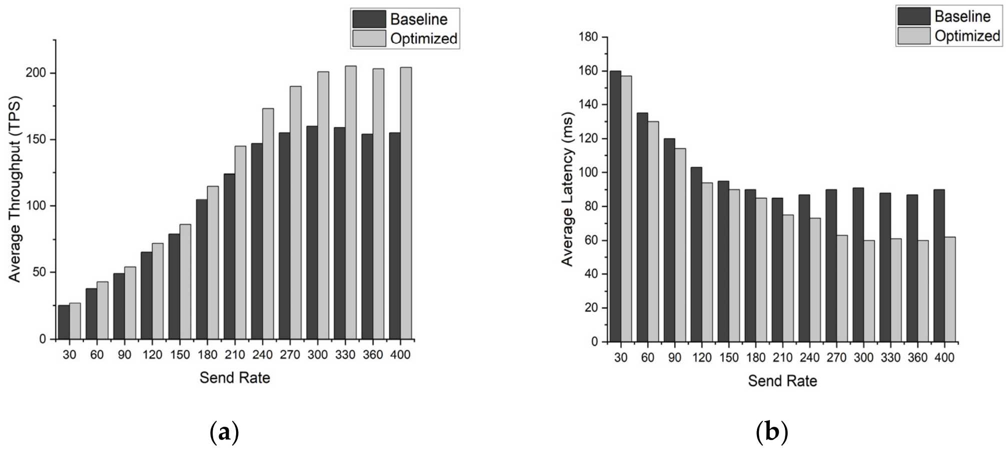


Figure 7. Average transaction throughput (**a**) and latency (**b**) with one TSO and one DSO.

Figure 8 compares the network latency and throughput of the proposed blockchain performance improvement mechanism based on learn-to-predict with the baseline network, with one TSO and two DSOs at varying transaction send rates between 30 and 400 tps. In this experiment, it can be seen that transaction throughput scaled linearly with send rate, up to about 210 tps. The transaction throughput of the learn-to-predict mechanism and the baseline were 140 and 179.3 tps, respectively, when the send rate was set to 400 tps, representing an 21.9% increase in transaction throughput. Similarly, when the send rate was adjusted to 400 tps, the transaction latency of the learn-to-predict mechanism and the baseline were 115 and 91 ms, respectively, representing a 20.8% reduction in transaction latency.

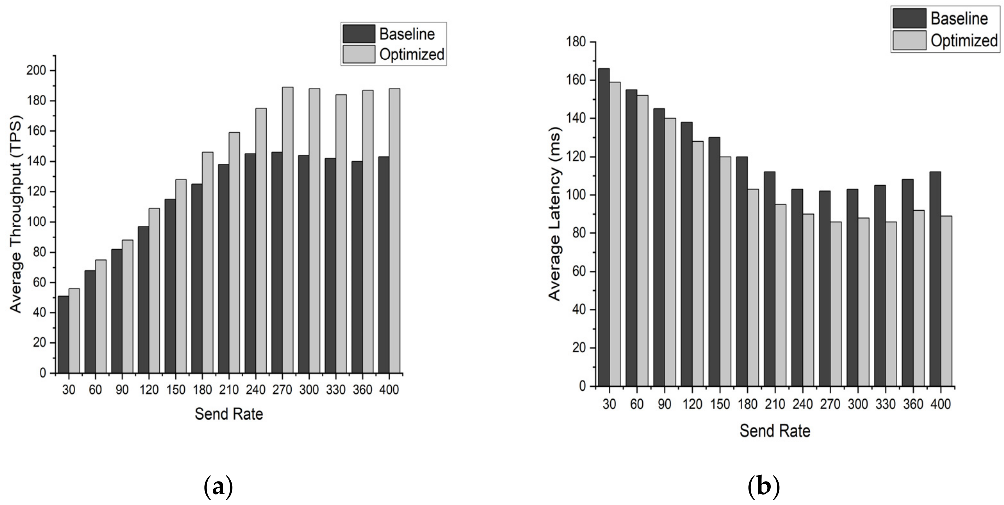
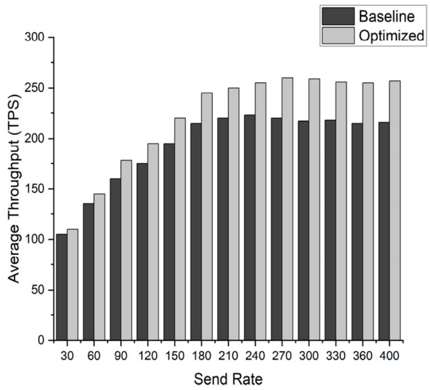
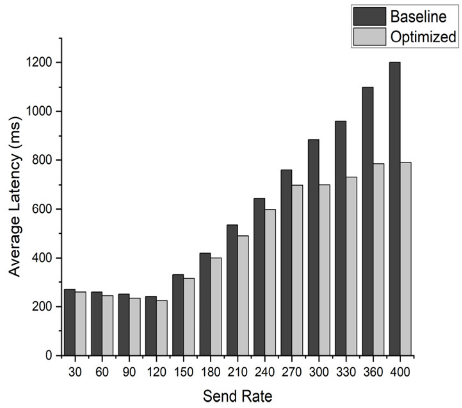


Figure 8. Average transaction throughput (**a**) and latency (**b**) with one TSO and two DSO.

Figure 9a compares the network using the proposed mechanism based on learn-to-predict with the baseline network over different transaction send rates to evaluate transaction throughput with one TSO and five DSOs (ranging from 30–400 tps). In this experiment, it can be seen that transaction throughput scaled linearly with the send rate up to about 210 tps. When the send rate was higher than this, transaction throughput growth slowed drastically and the system neared saturation. The transaction throughput of the learn-to-predict mechanism and the baseline were 221.5 and 263.4 tps, respectively, when the send rate was set to 400 tps, representing an 18.9% increase in transaction throughput.



(**a**)



(**b**)

Figure 9. Average transaction throughput (**a**) and latency (**b**) with one TSO and five DSO.

Figure 9b compares the network using the proposed transaction traffic control mechanism based on learn-to-predict with the baseline network over different transaction send rates to evaluate transaction latency with one TSO and five DSOs (ranging from 30 to 400 tps). When the send rate was adjusted to 400 tps, the transaction latency of the learn-to-predict mechanism and the baseline were 1200 and 790 ms, respectively, representing a 34.1% reduction in transaction latency.

The experimental findings in this section show that the suggested strategy is suitable to exchange data and information between different entities of the smart grid. This paper implemented a case study of a blockchain network based on data exchange within the smart grids. The impact of saturation on the transfer rate and efficiency of blockchain is significant. When a blockchain network is saturated, the transfer rate slows down, as each transaction competes for limited network resources. Furthermore, network saturation also effects the overall efficiency of the blockchain network by increasing the risk of network congestion. To mitigate the impact of saturation, as seen for the results, implementing optimization algorithms increases the transfer rate and efficiency of the network. The system is developed on a permission-based blockchain network called Hyperledger Fabric. This study proposes a learn-to-predict method for the performance enhancement of blockchain networks. The proposed study indicates that the system performance is enhanced by keeping the network throughput high and keeping low latency.

6. Conclusions and Future Work

This article presents a blockchain-based data exchange platform for the entities of smart grids, and its performance improved using a learn-to-predict ANN model. A use case for exchanging data within the smart grids is implemented on the Hyperledger Fabric network to evaluate the proposed approach. Most of the existing information and data exchange platforms are centralized, which leads to single-point failure vulnerabilities, malicious attacks, and altered data. Blockchain offers a decentralized solution to current system problems. Blockchain's decentralized consensus system can ensure trustworthy data transactions. This new proposed platform has the potential to improve TSO-DSO interoperability, allowing the overall system to run more efficiently in terms of supply security and congestion management. The suggested platform has potential applications to various other industries that require the exchange of information and data between users, such as smart cities, which aim to enhance the sustainability of urban infrastructure.

The experimental result shows that the proposed approach is suitable for exchanging data within the smart grids, and the performance of the blockchain network is enhanced when integrated with the learn-to-predict model. The results indicate that the overall throughput is improved with the increasing send rate, and the network latency is reduced. The experiments performed suggested that the proposed platform scales linearly by increasing the number of nodes. The results from Figures 7–9 suggests that the proposed ANN model for optimizing the blockchain network enables it to handle more transactions and users. The efficiency of our proposed platform is increased as the processing time for transactions is reduced. One of the limitations of the proposed platform is that at a certain send rate, the network latency and throughput become untenable because the peers become saturated, consuming all available system resources. Future work will test the network with more use case scenarios and test the impact of the proposed approach with more resources available to the network.

Author Contributions: Conceptualization, M.A. and G.T.; methodology, M.A. and G.T.; software, M.A.; validation, M.A., G.T. and Z.H.; formal analysis, M.A.; investigation, M.A., G.T. and Z.H.; writing—original draft preparation, M.A. and G.T.; writing—review and editing, M.A., G.T., Z.H., M.L. and C.S.L.; supervision, G.T.; project administration, M.A., G.T., Z.H., M.L. and C.S.L.; funding acquisition, G.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research was partially funded by the European Union's Horizon 2020 research and innovation program under grant agreement No. 774500.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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